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THE QUARTERLY JOURNAL OF
EXPERIMENTAL PSYCHOLOGY

Vol. VI 1954 Part 2

STRENGTH DURATION CURVES FOR ELECTRICAL STIMULATION OF THE HUMAN EYE

BY

C. I. HOWARTH

(From the Institute of Experimental Psychology, University of Oxford)

Baumgardt's surprising report of a minimum at about 30 milliseconds in the strength-duration curve for electrical stimulation of the human eye is confirmed. Arguments are presented against his explanation of the phenomenon.

An alternative hypothesis is developed: that the complex strength-duration curve is due to the interaction of on and off processes, which are separately excited by the make and break of the current: that these processes summate when separated by 30 milliseconds but are mutually inhibitory at 70 milliseconds: that these processes are the same as those known to be aroused by light. Two new experiments are designed to test this hypothesis, and the predicted result has been obtained from each.

Experiments are devised which show that the site of stimulation is the retina.

The accuracy of the method is discussed. Over the range 10 to 100 milliseconds distortion is found to be small. For shorter pulses distortion is to be expected in all cases, and it is suggested that the chronaxie is an expression merely of the condenser effect of the tissues. The use of this term should be discontinued in connection with stimulation through the skin.

Some parallels between these results and brightness comparison experiments with light are pointed out. The nature and location of the interaction is discussed.

I

Introduction

A new method of approach to many visual problems has recently been developed by Motokawa and his school (Motokawa, 1949, a, b & c, 1950, 1951; Gebhard, 1953). They have used the electrical threshold of phosphenes as an index of the excitability of the visual system and have discovered that this excitability is raised over a period of seconds after exposing the eye to a flash of light. This increase of excitability is related to colour processes. The electrical threshold is lowest at 1 second after a flash of red light, 2 seconds after a flash of green light, and 3 seconds after a flash of blue light (Motokawa, 1949a). The threshold is lowered still more when colour or brightness contrast can be expected. The method has been used to investigate two main problems: colour vision—particularly the old problem of the classes of colour receptors; and shape perception, by using the contrast phenomena. Motokawa claims that the method is capable of showing the part played by the retina in both these fields and supports this by experiments with frogs' and cats' eyes. (Motokawa, Iwama & Tukahara, 1950; Motokawa, Iwama & Ebe, 1952).

Unfortunately this work is almost completely unsupported so far by other workers. But this is not the only difficulty. When one reads the older literature on the electric phosphenes one finds that there has been almost no agreement on the simple electrophysiological properties. For example, there is a controversy about the effect of dark adaptation on the electrical threshold which has still not

been settled (Bouman, 1935; Achelis & Merkulow, 1930; Schwarz, 1947; Barlow, Kohn & Walsh, 1947; Abe, 1950); the chronaxie values quoted range from 0·5 to 20 milliseconds (Achelis & Merkulow, 1930; Bourguignon & Déjean, 1926; Verrijp, 1924; Iwama, 1949); and strength-frequency curves of almost infinite variety have been obtained (Rohracher, 1935; Schwarz, 1947; Abe, 1950; Barnett & Posner, 1941; Pollock & Meyer, 1938). Motokawa's school has investigated the chronaxie of the eye (Iwama, 1949) and the strength-frequency curve (Motokawa & Iwama, 1950; Abe, 1950; Motokawa & Ebe, 1952), but have suggested no explanation for the previous disagreements. In fact Motokawa is now in a minority of one about the shape of the strength-frequency curves. The number of unaccountable anomalies seems to be increasing rather than decreasing at the moment.

In addition to this there must be many doubts about the accuracy of a method of stimulation with electrodes so far away from the excitable tissue. A great deal of the imposed current must be missing the nervous structures completely. Any change in the amount of this wastage will of course appear as a raising or lowering of the threshold. There has been no systematic approach to this problem.

The site of stimulation is unknown. Motokawa considers that it is somewhere in the retina because he can repeat some of his results with excised eyes. Iwama (1949) considers that it is the ganglion cells which are excited because of the *long* chronaxie which he finds. Copolongo (1948) on the other hand thinks that central structures, even the cortex, are involved because, he claims, blind subjects experience the phosphene and have the same *short* chronaxie as normal subjects. Baumgardt (1951b) on anatomical grounds considers that it is the optic nerve which is stimulated close to its entry into the eye.

Recently Baumgardt (1951a) has shown that the strength-duration curve for electrical stimulation of the eye has more than normal interest. This work, although less well known than that of Motokawa seems to be just as important. Baumgardt claims that the method shows up very clearly the existence of a slow inhibitory process in the visual system. Because of this the strength-duration curve is complex with the threshold for long pulses being, surprisingly, higher than that for shorter pulses. This complexity has been found by no other worker, but in view of the apparent relationship between contrast and inhibition it was thought that there might be a relationship between these findings of Baumgardt and those of Motokawa.

On these grounds it was thought useful to investigate again the simple strength-duration curve for the human eye. The immediate aim of the work was to discover the nature and cause of the complexity in this curve and to test Baumgardt's hypothesis about it. It was hoped at the same time to find the site of stimulation, test the accuracy of the method and clear up some of the previous discrepancies.

II

Apparatus

Except for the single experiment reported using constant voltage, all the stimulation was done by means of constant current generators. The arguments in favour of this method of stimulation are given later in the text. Most of the results have been obtained from a specially constructed output unit giving a constant direct current from 1–10,000 microamps provided the voltage developed is less than 200 volts. When constant voltage measurements were required a 400 ohm resistance was placed in parallel with the subject whose resistance is about 5000 ohms. Attached to the stimulator was a waveform generator which gave most of the pulses needed. To obtain two pulses in opposite directions a Lucas pendulum contact breaker was incorporated in the apparatus. A 300 volt source with a series resistance of $1\frac{1}{2}$ megohms gave a constant current pulse of

7 milliseconds duration. At a given interval before or after this pulse the main stimulus generator could be triggered and gave a 10 millisecond pulse of accurately adjusted intensity.

Ag/AgCl and $Zn/ZnSO_4$ electrodes were used at first but such precautions were found unnecessary when using constant current pulses. Large aluminium electrodes padded with saline soaked cotton wool were used normally. A variety of positions was tried including wick and contact lens electrodes directly on the eye. No differences could be detected in the results from the various methods and generally one large electrode on the forehead and another on the hand was used. $Zn/ZnSO_4$ electrodes were used for the constant voltage stimulation.

A Cossor double beam oscilloscope was used to check the waveforms produced and to estimate the capacity of the tissue condensers.

Method

The method used was essentially that developed by Motokawa and very fully described in his papers. The basic measurement is the phosphene threshold. The phosphene is easily seen by nearly all subjects at about 300 microamps. The phosphene is an unfamiliar experience, and it is always necessary to give the subjects a good look at it before they proceed to the threshold determination. The procedure adopted for this is always the same. The strength of the current is reduced in steps of 10 microamperes. At each current strength the subject is warned about half a second before receiving the stimulus. Usually the experimenter says "coming" and then presses a button which triggers the stimulator. More mechanical and impersonal procedures have been tried; they seem to be without effect on the results and are in general too cumbersome and inflexible. On each presentation of the stimulus the subject reports "yes" or "no" depending on whether or not the phosphene is seen. If the answer is "yes" the strength of the current is reduced one step. If the answer is "no" the stimulus is repeated at the same intensity. If more than half the answers at this intensity are "yes" the intensity is again lowered. If 3 successive "nos" occur the series is terminated and the intensity one step above is taken as the threshold. In general subjects make up their minds quite definitely when the stimulus is no longer visible, and very little time is wasted saying alternately "yes" and "no." When this does occur it is usually because the subject is trying too hard to see the last trace of the phosphene and is unable to distinguish it from the entoptic illumination. This is much more likely to occur in the dark. None of the author's subjects could approach the accuracy reported by Motokawa for the dark adapted eye. For the light adapted eye the task is an easy one and a very satisfactory degree of accuracy is attained by most subjects.

A set of stimuli always starts well above the threshold. The actual amount above the threshold is varied in a random manner. The speed at which the stimuli are presented is adjusted to give the subject the least strain. Usually a rhythm of presentation develops with the stimuli following each other at intervals of 2 to 10 seconds. Blinking interferes considerably with the phosphene but the rhythmic presentation, together with the half second warning before each stimulus, allows the subject to inhibit his blinking at the moment when the stimulus is given. Motokawa has shown that the speed at which the stimuli are presented affects the threshold. But the amount of this effect is small compared with the size of the phenomena investigated and apart from the regular presentation of the stimuli no attempt has been made to control this factor. The threshold is always approached from above. Determinations using increasing current strengths have been tried. In general a slightly higher threshold results but the task is much more difficult under these conditions.

At the beginning of the investigation a diffusing screen illuminated from behind was used and the effect of different illuminations investigated. No change in the threshold could be found over a very wide range from bright sunlight to near the photopic threshold. Below the photopic threshold a big change occurred which is described later. Nothing else of interest was found so the investigation is not reported in full. It is mentioned here as the justification for the absence of accurate control of illumination in the later experiments. The general illumination of the room never fell below 3 millilamberts and the subjects were asked to fixate a spot on the whitewashed laboratory wall. This was by no means uniformly illuminated but accuracy was better and fatigue less under these conditions than when using a diffusing screen.

Subjects vary considerably in their ability to repeat the threshold determinations.

TABLE I

CONDITION A

	Time "t" milliseconds											
Subject	10	15	20	25	30	40	50	60	70	80	90	100
CIH	165	125	112	97	100	118	140	165	175	—	175	—
DB	175	150	120	102	100	107	120	160	173	183	190	190
H.B.G. ..	130	120	108	105	100	110	125	145	155	160	155	160
Average ..	157	132	113	102	100	112	128	157	167	171	173	175

TABLE II

CONDITION B

	Time "t" milliseconds											
Subject	10	15	20	25	30	40	50	60	70	80	90	100
CIH	136	114	104	97	100	119	147	149	150	150	130	138
DB	—	115	107	—	100	107	132	132	132	—	136	136
P	133	117	105	102	100	109	129	135	126	—	120	129
Average ..	135	115	106	99	100	112	136	139	136	—	129	135

TABLE III

CONDITION C

	Time "t" milliseconds									
Subject	10	20	30	40	50	60	70	80	90	100
CIH	159	131	100	90	95	107	120	124	113	107
DB	177	122	100	100	108	126	137	130	130	130
JP	131	105	100	100	107	121	131	128	138	140
Average ..	155	119	100	97	103	118	129	127	127	126

Tables I, II and III.

These are the results from which curves A, B and C of Figure I are plotted. Each figure represents the average of at least two determinations. To enable the results from different subjects to be pooled the thresholds are reduced to a percentage of the threshold for "t" = 30 milliseconds.

Usually however the scatter obtained is less than 20 per cent. and in most cases a very much higher accuracy can be attained after very little practice.

As the session proceeds there is occasionally a slight fall in the threshold values after about 5 minutes. Very commonly if the subjects are kept longer than ¾-hour a sudden sharp rise in the threshold occurs. Once this has started it tends to continue and these readings are always discarded. To check that neither of these phenomena is affecting the shape of the curve, the mid-point (usually at 30 milliseconds) is checked repeatedly during the course of the experiment. If any change occurs the intermediate readings are always discarded. As a further check against slight drift of the threshold the points on the curve are always determined in series in both directions. In general there is remarkably little drift during the usual experimental session of half an hour.

The threshold tends to vary somewhat from day to day in the same subject, over a range sometimes as great as 50 per cent. but usually the readings are stable within about 5 per cent. provided the placing of the electrodes is unchanged. When results from different days are pooled allowance is always made for this effect. In the results reported the thresholds are given as a percentage of the threshold for the 30-millisecond pulse.

Many subjects have been used. None of them have given results contrary to those predicted by the author's hypothesis. Two out of about 30 have found the task extremely difficult and were unable to give sufficiently repeatable results for any curve to be obtained. This was in one case due to a sleepless night, in the other no adequate reason could be found. The results reported are not selected because they are better than most, but because they are from subjects who were prepared to come several times, and who have been tested over the full range of the curve reported.

III

Experiments

Strength-duration curve

The strength-duration curve for the human eye was done repeatedly and carefully using constant current square pulses. (Table I, Figure 1 curve A). The results amply confirm those of Baumgardt (1951a). There was always an increase in the threshold current for pulses longer than 30 milliseconds. The amount of this rise varied from person to person, in some cases being as much as 75 per cent. and in others only 30 per cent. The threshold frequently fell again for pulses longer than 70 milliseconds, but this part of the curve has not been accurately explored.

Baumgardt's Hypothesis

Baumgardt has pointed out that the raising of the threshold for pulses longer than 30 milliseconds can only be due to an active process, presumably in the nerve tissue. Such an effect could not be produced by any amount of distortion of the pulse by the tissues surrounding the eye (discussed on page 56). He has postulated (1951a) that a slowly developing inhibitory process is responsible for the rise in threshold. This hypothesis had already been very fully developed by Baumgardt and Segal (1947) in connection with some experiments with light.

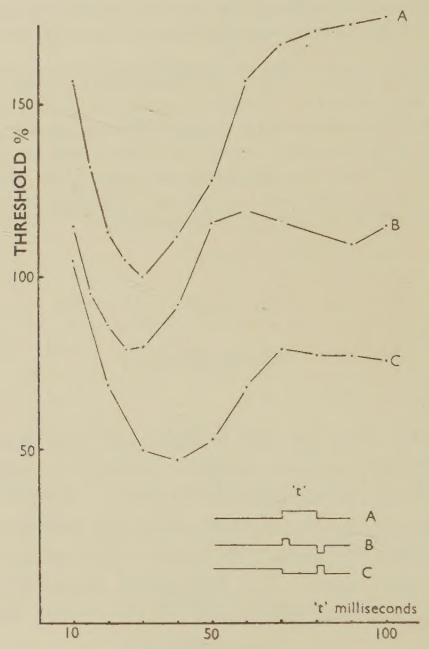
The following is an extract from their summary of the paper. "The stimulus arouses in an excitable element or system two antagonistic processes, one facilitatory and developing rapidly, the other inhibitory, released by the first and developing later and probably more slowly. Because of this difference in the time constants the sensation passes through two successive stages. During the first the behaviour of the nervous cell is primarily governed by the growth of the facilitatory function; during the second the facilitation has reached a maximum while the inhibitory function is still growing. An extra influx of energy increases most the developing

process. As a result the initial supernormal phase is followed by a subnormal phase."

The inhibitory process is "retroactive" so that the strength of the sensation does not depend on the maximum level of excitation reached by the system but is an average of the total excitation.

This hypothesis seems to have difficulty in accounting in the same terms for the strength-duration curves for single and for double pulse stimulation. Baumgardt (1951b) used two short pulses of constant duration with a varied interval between them. He found the threshold, and therefore the inhibition, to be a

FIGURE 1.



Threshold as a function of time "t" for the various wave forms shown.

The threshold is given as a percentage of the threshold for t = 30 milliseconds. Curve B is displaced downwards 20 per cent. and curve C 50 per cent.

Each point represents the average for the three subjects in Tables I, II and III.

maximum at 30 milliseconds. The present author has completely confirmed Baumgardt's experimental results (4 subjects Figure 2). However when the theory is applied to the strength-duration curve for a single pulse, inhibition is expected to be at a maximum when the upward slope of the curve is greatest, i.e. at about 45 milliseconds. One would like to know whether this is a real difference which needs to be explained or whether it is the result of a fault in the theory.

This theory is also weak because of the number of specific but untested assumptions which it makes. It is hard to think what kind of experiments would be capable of demonstrating the slowly developing inhibitory process which is also retroactive. An alternative hypothesis has been developed which is simpler, more in accord with known physiological processes and seems to have greater predictive and explanatory power. It is also more easily testable by experiment.

A New Hypothesis

The new hypothesis explains the complexity of the curve as follows:—

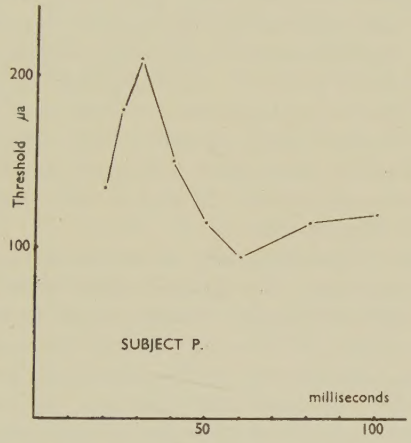
(i) The single square electrical pulse is being converted by adaptation into two separate pulses of opposite polarity, one occurring when the current is switched on and the other when it is switched off.

(ii) These pulses separately excite two processes called "on" and "off" processes.

(iii) These processes later interact by summation or inhibition, the nature of the interaction depending on the time interval between them. At 30 milliseconds they summate maximally whereas at 70 milliseconds they are mutually inhibitory.

(iv) These "on" and "off" processes are the same as those aroused by light.

FIGURE 2.



Threshold as a function of the time separating two 10 millisecond pulses. Similar results have been obtained from 3 other subjects.

This hypothesis was suggested in the first place by the symmetry between the strength-duration curve for a single square pulse (Figure 1 A) and the strength-duration curve for two 10 millisecond pulses with a varied interval between them. (Figure 2). The first has a minimum at 30 milliseconds and the second a maximum at the same interval. It suggested that there was a great similarity between the two conditions of stimulations from the point of view of the nervous structures involved. This could only be the case if the continuous stimulation of the single prolonged pulse were converted into periodic stimulation by the adaptation of the tissues. Such adaptation, as is well known, will be followed by a rebound response when the current is switched off. Thus the single prolonged pulse will be converted into two separate pulses of opposite polarity.

Another indication that this might be the case is that the very accurate work of Bourguignon and Déjean (1926) and of Achelis and Merkulow (1930) using condenser shocks, did not show the raised threshold for longer pulses. This may be because condensers produce a pulse which does not switch off sharply but which dies away exponentially. There will be no "off" effect of the kind which might be found with constant current or constant voltage stimulation with square pulses. This made it

seem likely that the sharp "off" effect was responsible for the complexity of the curve.

Tests of the Hypothesis

(i) The next experiment tested this hypothesis by reproducing the postulated conditions. A 7-millisecond anodal pulse, 80 per cent. of the threshold intensity, was followed after a varied interval by a 10-millisecond cathodal pulse whose intensity could be continuously varied. The hypothesis predicts a minimal threshold when the two are 30 milliseconds apart. This prediction is completely confirmed. In fact the whole curve under these conditions follows closely the strength-duration curve for a single pulse. (Table II, Figure 1 B).

So far no variation in the curve has been detected when the polarities of the two pulses are exchanged, nor when the order of the fixed and variable pulses is changed. The threshold at 30 milliseconds is always less than the threshold for the 10-millisecond pulse alone, and at 70 milliseconds is always greater.

(ii) Although this explanation may hold good for periodic stimuli, it may still not be wholly true for the response to continuous stimulation. To see whether there really is an "off" response after continuous stimulation another experiment was devised. A subthreshold pulse of 75 milliseconds duration was followed at a varied interval by a 10-millisecond pulse of 50 per cent. greater intensity. The present hypothesis predicts three separate "on," "off," "on," processes; the interval between the last two alone is varied and one must predict a minimum threshold when they are 30 milliseconds apart. In fact a minimum is found at about 40 milliseconds. (Table III, Figure 1 C).

This discrepancy is not great and may be attributed to the disturbing effect of the first immobile "on" response. Further, all other hypotheses fail to predict any minimum at all. Any slow inhibitory process ought to be well under way after 75 milliseconds. Alternatively, if this were simply the same kind of situation as that shown in Figure 2 a steady rise in the threshold would be expected. This seems then fairly conclusive evidence that separate "on" and "off" processes are aroused, that they interact, and that they are of opposite polarity. If this is the case, they are very similar to the "on" and "off" processes already known as the retina's response to light.(Kuffler, 1953; Gernandt & Granit, 1947; Barlow, 1953; Thomson, 1953; Hartline, 1938; Granit, 1947), and they are in fact almost certainly the same (see Discussion). Granit (1946) has produced experimental evidence of the opposite electrical polarity of the "on" and "off" elements.

All the previous work on the "on" and "off" fibres has been done with microelectrodes and their interaction has not been fully investigated because of the technical difficulty of the experiments (see Thomson, 1953). Their temporal characteristics are quite unknown, nor do we know in what sense they interact. The experiments seem to show that, in the retina at least, they are always antagonistic. (Kuffler, 1953). But this applies only to prolonged and simultaneous stimulation of adjacent areas of the retina. The present series of experiments seems to show that the interaction may be complex and important, and, by showing the time course of the interaction, provides a good grounding for further experimental investigation of the problem.

Site of Stimulation

The present gross experiments do not allow the separation of the different possible levels of interaction. The "on" and "off" fibres could interact beyond the optic nerve either in the thalamus or in the cortex. Alternatively, the interaction

could be taking place within the retina itself at a preganglionic level. The site of stimulation is very important in this connection. If the point of stimulation is the optic nerve (as maintained by Baumgardt) or the optic centres of the brain (as maintained by Copolongo) the interaction could not possibly take place within the retina. However the following experiments seem to eliminate both these possibilities. (The first experiment was suggested by Dr. F. W. Campbell of the Oxford Eye Hospital.)

(i) Pressure on the eyeball by occlusion of the retinal circulation leads to a darkening of the field of vision. This has been shown to be due to a temporary interruption of nervous conduction within the retina, leaving the photosensitive layer and the optic nerve itself intact. (Craik, 1940). The electrical threshold under these conditions is very much raised and does not seem to have the characteristic threshold-time curve of the normal condition (2 subjects). This is a most unpleasant experiment to do, so naturally not many readings were taken for each subject. However the threshold was raised by a factor of ten, so that the difference found is certainly reliable. The best explanation of this result is that under normal conditions it is the retina itself which is stimulated but when conduction through this is blocked, the optic nerve fibres react, but at a higher threshold.

(ii) In subjects with detachment of the retina a very similar disability is found which again is largely confined to the retina. They do have also some degeneration of the optic nerve but this is not usually very great. Two subjects were used and in both cases results almost identical with the above were found. The threshold was raised by a factor of ten and no sign could be found of any minimum in the strength duration curve. The chronaxie was probably of the order of a few milliseconds similar to that found for an ordinary motor or sensory nerve (see page 56). Here again the best explanation seems to be that it is the optic nerve which is being stimulated.

(iii) Despite the results of Copolongo (1948), blind subjects with atrophy of the optic nerve do not apparently experience the phosphene at any bearable intensity of stimulation (2 subjects). One of the subjects was used to electrical shocks in his work as a physiotherapist and was prepared to stand a current of 8 milliamps. He was still unable to see the phosphene although this is a frighteningly high current. Thus stimulation must normally be taking place below the level of the thalamus. The only likely explanation for Copolongo's results is that he was giving his patients such a severe shock that they saw "stars."

(iv) Another suggestive result is that in the dark adapted eye the strength-duration curve does not rise for long durations (5 subjects, Figure 3). It would be rash to offer a complete explanation of this, but it is obvious that the biggest changes in dark adaptation occur in the retina itself, so that here again a retinal change has resulted in a big change in the excitability. The mechanism of this change is probably related to the finding of Motokawa and Iwama (1949) and of Bouman (1935), that the ability of the eye to adapt to an electrical current is very much decreased in the dark adapted eye. If this is the case, there would be no "off" response when the current is switched off. As a result the threshold for short pulses is raised because of the absence of summation, and the threshold for long pulses is lowered because of the absence of any inhibitory "off" process. This is also in line with the established connection between the "on" fibres and the rods.

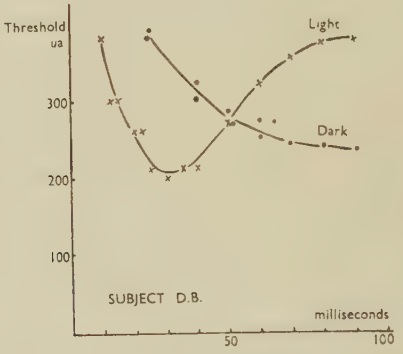
Incidently these results may go a long way towards settling the controversy about the effect of dark adaptation on the electrical threshold. There is first of all a very great deal of individual variation. But a common result is the one shown

in Figure 3 where the threshold is raised in the dark for short pulses but lowered for longer ones.

These four experiments make it almost certain that the site of stimulation is the retina. The work of Bogoslowski and Ségal (1947, a & b) has already supported this. They showed that the spatial characteristics of the phosphene are what would be expected from the spread of current through the retina along the path of least resistance. These spatial characteristics of the phosphene would be hard to understand if the site of stimulation were anywhere else.

There is nothing in any of the above experiments to show where the interaction between the "on" and "off" processes takes place. They do show however that since the site of stimulation is in the retina, the interaction could also be taking place there, and the time relations found could be characteristic of the retina itself.

FIGURE 3.



Threshold as a function of time for single pulses in the light adapted eye and in the completely dark adapted eye. Similar results have been obtained from 4 other subjects.

The Accuracy of the Method

Because of previous disagreement among workers in this field, it would be undesirable to add yet another new result without some discussion of the research technique.

The results of this investigation are extremely repeatable. It was not felt necessary to use any function like Motokawa's ξ to eliminate the effect of changes in skin resistance. This was thought to be due to the use of constant current stimulation. Many of the previously reported extremely varied results may have been due to the use of voltage measures of threshold or of rather inefficient current generators.

Even if the results are extremely repeatable, they may still be inaccurate or misleading, because of distortion of the electrical pulse as it passes through the skin and other tissues surrounding the eye. There is evidence that such distortion does occur over a period of about 10 milliseconds from the beginning of the pulse. The big disagreements, in the previously reported values of the chronaxie, are due to this effect. Workers using condenser shock stimulation have obtained chronaxies of 1 to 2 milliseconds (Achelis and Merkulow, 1930); Bourguignon and Déjean, 1926). Others using constant current stimulation have found chronaxies of about 10 milliseconds. (Verrijp, 1924; Iwama, 1949). As Baumgardt has pointed out (1951a), the chronaxie concept is not applicable to strength duration curves with a trough

in them. He has used a similar measure, the "pseudochronaxie," to allow the same kind of comparison to be made with the results of other workers. Both he and the present author find "pseudochronaxies" of the same order as the chronaxies of Verrijp and Iwama.

The short chronaxies found using condenser shocks are thought to be due to the electrical capacity of the skin in series with the electrodes. If a constant voltage pulse is passed through a condenser the initial current will be very great, but will fall off rapidly as the opposing potential is built up. As a result, the longer pulses will be relatively ineffective, the rheobase will be raised and the chronaxie consequently shortened. If a condenser shock is used the effect will be still greater and the chronaxie still shorter. This argument leads to the specific prediction that the chronaxie found using constant voltage will be intermediate between the extremes with constant current and condenser shocks. This prediction was confirmed on two subjects for whom "pseudochronaxies" of about 6 milliseconds were obtained.

The effect amounts to a distortion of the constant voltage pulse by the series condensers of the skin. Constant current pulses can not be distorted by series condensers but could be distorted by parallel condensers. The effect could be either a raising or a lowering of the relative value of the rheobase with consequent shortening or lengthening of the chronaxie. Chronaxie is therefore a meaningless term in connection with the electrical stimulation of the eye through the skin.

Distortion is not appreciable over the range (10 to 100 milliseconds), of the present experiments. This is demonstrated in three different ways.

(1) The shape of the curve is essentially the same under constant voltage conditions.

(2) The shape of the curve is not changed when contact lens electrodes are used. Only one-tenth the amount of current is needed under these conditions, showing that at least nine-tenths of the current is by-passing the retina under the ordinary conditions of stimulation.

(3) When the voltage developed across the electrodes is applied to the plates of a cathode ray oscilloscope it is found to reach a maximum within 10 milliseconds. This shows that all the tissue condensers are fully charged within that time. Beyond this the tissues will act as a resistance network and will not distort the pulse.

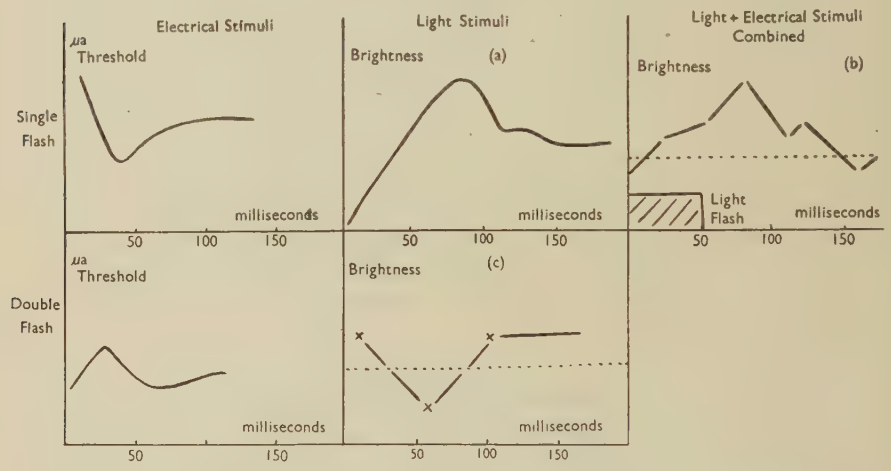
IV

Discussion

If the above arguments are valid, and there really is an interaction between "on" and "off" processes, one would expect the same mechanism to operate in response to light stimulation. There is no evidence for such a mechanism to be found in any of the very accurately carried out light-threshold experiments. This is probably because the slowness of the photochemical processes prevents the development of sharp "on" and "off" responses to threshold light stimulation. However when the intensity of the light is increased the photochemical reactions are faster, and sharp "on" and "off" processes can occur (Granit, 1947, p. 151). Thus although no light threshold experiments show these time relations a whole series of brightness comparison experiments do. The minimum in the threshold curve at 30 milliseconds corresponds to the well known (but rather neglected) Broca and Sultzer (1902) phenomenon (Figure 4). In these experiments it was shown that at a given intensity a light flash of only 60 milliseconds appears brighter than one lasting 200 milliseconds. Baumgardt and Segal (1946b) have shown that this difference affects the

reaction time and claim that this shows the "retroactive" nature of their slow inhibitory process. Comparable results have been found by Bogoslowski and Segal (1945, Figure 4) for the interaction of light and electrical current. In this experiment the effect of an electrical current through the eye on the brightness of a 50-millisecond flash of light was assessed on a 7-point subjective scale. No comparison light was used. As a result this experiment is not so accurate as that of Broca and Sulzer, but it is accurate enough to show that very much the same kind of curve is obtained and also to show that the same electrical pulse may be excitatory or inhibitory depending on the time between it and the light flash.

FIGURE 4.



Comparison of strength-duration curves for various forms of light and electrical stimulation.

(*a*) *Broca & Sulzer.* 1902. The brightness of a single flash of light of duration "t."
(*b*) *Bogoslowski & Segal.* 1945. The change in the brightness of a 50 millisecond flash produced by the "make" of a cathodal current through the eye at time "t."
(*c*) *Baumgardt & Segal.* 1946 (a). The fused brightness of two 10 millisecond flashes of light separated by time "t."

Baumgardt and Segal (1946, see Figure 4) performed a double-flash experiment with light. They used two 10-millisecond superimposed flashes of light. The first flash was smaller and within the area of the second. When they were only 10 milliseconds apart the central area appeared lighter than the rest. When they were 50 milliseconds apart it appeared dark. At about 100 milliseconds the two flashes appeared separate and the central area was bright again. This result is comparable with Baumgardt's (1951b) experiment on the threshold for two 10-millisecond electrical pulses.

All these experiments have been discussed by Baumgardt and Segal (1947) and their theory applied to them. The present author's hypothesis is equally capable of explaining them.

The evidence is not yet sufficient for much to be said about the site of the interaction, or the reasons for the peculiar time relations which are found. There are however two attractive pieces of speculation in the literature which should perhaps be discussed. The first is to be found in Adrian's "Basis of Sensation" (1928).

Here the Broca and Sulzer curve is presented side by side with the Adrian and Matthews curve, showing the frequency of impulses in the optic nerve of the conger eel following the onset of a flash of light. From the similarity in the two curves one is presumably expected to infer a similarity of mechanism. If this comparison were valid the site of interaction would be placed firmly in the retina. But since one curve shows the intensity of the response as a function of the time relations of the stimulus while the other gives it as a function of the time relations of the response, these curves cannot be directly compared. There is certainly no reason to expect them to be due to the same mechanism.

The second is the suggestion by Bartley (1939) that the enhanced brightness of a slowly flashing light (Brücke effect) is due to the driving of the alpha rhythm by the stimulus. If the response to a single flash of light is double, as is suggested in this paper, it is conceivable that such a driving effect could take place for the single flash as well as for repeated flashes. This would be a particularly attractive theory because it would account for the effects of changing the polarity of the second of the two pulses in the double pulse experiments. Unfortunately although the times found in the experiments with light are of the right order, the 30-millisecond minimum is outside the known range of the alpha rhythm. The same kind of theory might still be used if a centre with the appropriate periodicity could be found in the visual system. There are other indications that this sort of "resonance" theory would be useful. For example, Motokawa and Iwama (1950) have found several "resonant" minima in the strength-frequency curve for A.C. stimulation of the eye and Bartley (1951) has shown that the apparent frequency of a just perceptibly flickering light is always about 18 cps. The present author has evidence that the frequency of even quite strongly flickering phosphenes always appears to be about 18 cps. So far there is no reason to think that the retina has a spontaneous rhythm of this frequency, so if this kind of explanation is the right one some central system must be supposed to be the site of the interaction. There are however other possible mechanisms and a full discussion of them should be left until more evidence is available.

The longer time constants found in the experiments with light are puzzling. They seem to be due in some way to the "blurring" of the stimulus by the photochemical process. This is shown by the shortening of the time constants as the intensity of the light is increased. With increasing intensity of the light stimulus the electrical events at the retina will become sharper in onset and in form. The more rapid these events become the more they will approach the ideal form which is the result of square wave electrical stimulation.

It is worth noting that one of the simplest ways of explaining the effects discussed in this paper would be to postulate interaction in the retina of the electrical potentials which develop in response to both light and electrical stimulation. If the "off" response were an inverted form of the triphasic "on" response recently found by Cobb and Morton (1952), then the interaction of the "on" and "off" responses would be of exactly the type required. The interaction of two triphasic waves inverted in the m–w sense would give the required succession of inhibition–summation–inhibition as the amount of overlap between them is decreased. This amounts to a prediction of the form of the "off" response in the human retinogram which the author intends to investigate.

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RESPONSE–DURATION OF LEVER PRESSING IN THE RAT

BY

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Two aspects of the lever-holding behaviour of rats in a Skinner-box have been analysed: firstly, the changes in the duration of the responses during the acquisition and experimental extinction phase, and, secondly, the bunching of responses during the experimental extinction phase. The response-durations on the first few acquisition trials were found to be bimodally distributed, but to become stabilized at 0·42 seconds as practice increased. During experimental extinction response-durations increased. The rate of increase depended on the conditions of secondary reward. Rats who had the source of secondary reward removed, or restricted, yielded a steeper slope than those who responded under the same conditions of secondary reward as during training.

The analysis of the extinction scores revealed that unrewarded responses were emitted in groups. Response-group latencies were shown to progress as a positive function of the number of response-groups, and the average response-duration for consecutive response-groups to increase progressively. The slope of the duration curve plotted for successive response-groups increased, and this was related to an increase in the value of the time-intercept for successive response-groups.

I

Introduction

Hungry laboratory rats are placed in a Skinner-box in which food is secured by pressing a light, protruding lever. When activated the food magazine emits a sharp, audible click. It has been found that during a test period in which no food is delivered, animals hearing the click will make more responses than those who have this source of stimulation removed. The click is said to have become a secondary reward.

The present paper describes an experiment which showed that the duration of the lever-holding response increases during an extended period of unrewarded responding. The rate of the change in the duration was found to be related to the prevailing secondary-reward conditions. Attention is also drawn to the emergence of response-groups, and an attempt is made to relate response-groups to response-durations. These findings shed further light on the character of the rat's behaviour in the Skinner-box and the factors which determine it.

Skinner and others had previously noted that unrewarded responses occur spasmodically, at irregular intervals, and have maintained that this indicates agitated behaviour produced by an emotional effect which is set up through "lack of reinforce ment" of a rigorously built-up behaviour chain. This finding runs counter to the view that responses are emitted at a constant rate, and confounds attempts to describe the rate of lever-pressing in terms of smooth, negatively accelerated curves. It obliges us to analyse the phenomenon of response-grouping more closely. The present paper includes some suggestions as to how this objective may be accomplished.

II

Experimental Design, Apparatus and Procedure

The experimental design of this study is detailed in Table I. There were five experimental groups of three months old, hooded male rats. The experimental conditions during learning and experimental extinction trials are outlined in Table I. *Group A* (7 animals) received a buzz which lasted for the total duration of each rewarded response

but had this source of stimulation removed during unrewarded responding trials. *Groups B and C* (6 and 7 animals respectively) received a buzz for approximately 0·5 seconds irrespective of the duration of the rewarded response, though Group C received a buzz for the total time the lever was depressed during unrewarded responding as against 0·5 seconds for Group B. *Group D* (4 animals) had the procedure for Group C reversed, i.e. a buzz for duration of rewarded response and 0·5 seconds for each unrewarded response was given, whilst *Group E* (4 animals) obtained a buzz for the total period of lever-pressing during rewarded and unrewarded responding.

TABLE I

Group	*No. of animals*	*Number of rewarded responses*	*Phase I Stimulus conditions during rewarded responses*	*Phase II Stimulus conditions during unrewarded responses*
A	7	90	0·5 seconds buzz	no buzz
B	6	90	0·5 seconds buzz	0·5 seconds buzz per response
C	7	90	0·5 seconds buzz	buzz for duration of response
D	4	90	buzz for duration of response	0·5 seconds buzz per response
E	4	90	buzz for duration of response	buzz for duration of response

Apparatus

The apparatus used in this experiment was a modified Skinner-box, 1 ft. in all dimensions. The modifications were as follows: (*a*) the lever, a 1 in. square brass plate protruding 1¾ in. into the box, was fixed 5 in. to the right of a semi-circular food trough. This forced the animal to shuttle between lever and trough. A pressure of 5 gms. was required to depress the lever. (*b*) A new pellet-delivery machine, described in detail in a previous paper (Hurwitz, 1953) was used in this study. Though the machine is almost noiseless the buzz has been introduced to cloak any noise emitted by it. (*c*) The apparatus was permanently fixed in a sound-resistant case.

Records

Lever-pressing responses were recorded on a paper tape moving at 1 cm. per sec. This device presented the data in terms of (*a*) the *rate* of responding, (*b*) the *duration* of each response and (*c*) the *time interval* between consecutive responses.

Procedure

The experimental procedure followed the customary pattern. For the first five days the animals were fed once every 22 hours on wet mash and cod-liver oil. On the 5th day of the feeding schedule the rat was allowed 20 minutes exploration in the apparatus after the customary 2-hours feeding. The following day it was placed in the apparatus before normal feeding, and allowed to eat 10 pellets of food. Each pellet weighed approximately 0·05 gms. and measured ¼ in. × ⅛ in.

The animal was then withdrawn from the apparatus and returned to its feeding cage. On the following day it was once more introduced into the apparatus before the 2-hour feeding session. Ten pellets lay in the food trough. After the 7th pellet had been eaten, the experimenter delivered 30 pellets into the trough separately by operating an external switch which activated the feeding machine. Each pellet was accompanied by a 0·5 second buzz.

On the seventh day, the lever was connected to the food delivery machine. The animal was retained in the apparatus until it had obtained 30 pellets by pressing the lever. The training session was followed by an hour-and-a-half feeding in the cage.

A further learning session involving 60 pellets followed on the next day. On the ninth, and final day, no pellets were inserted into the food-magazine of the feeder. Unrewarded responding was continued until a period of 4 minutes elapsed during which no lever responses were recorded.

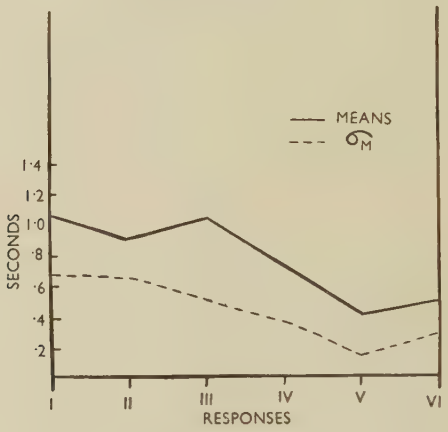
III

Analysis of the Results

Response-duration during rewarded responding

(*a*) In order to determine whether the duration of the response underwent a change as learning proceeded, the first 30 rewarded lever-responses made by each of the rats were analysed. To facilitate statistical treatment, the responses were grouped into units of 5, and the means computed. Figure I summarizes the results.

FIGURE 1.



(in units of 5)

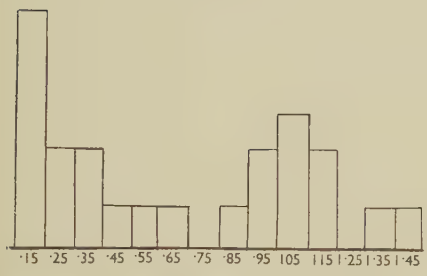
The unbroken line represents the means of the response-durations for all 28 animals. The broken line represents the standard deviation from the means. Both curves are decelerated, with the means stabilizing at 0·42 seconds. As a check on the reliability of this lower limit, a similar analysis was made for responses 30–60 and 60–90. This showed that the mean had increased to 0·55 seconds though the former analysis is in close agreement with the means computed for the first 30 responses, 0·47 seconds. The behavioural fact here described, that the duration scores of massed responses is an accelerated function of the number of responses made may well be due to a complicity of factors such as fatigue, satiation and the concomittant diminution of drive-intensity, and the general conditions of responding. This phenomenon has been more thoroughly studied during the past few months and the results of this investigation will become available in due course. Figure I also illustrates the decrease in the variability of the mean scores (broken lines). Further reference to this aspect of the data is made in section (c).

(*b*) It will be remembered that the five experimental groups fall into two groups with respect to the secondary-reward conditions obtaining during the first phase of the experiment. Groups A, B and C received a buzz lasting approximately 0·5 seconds for each lever response made, as against Groups D and E for which the buzzer sounded for as long as the lever was held down. The analysis of this data

suggests that the difference in the secondary-reward conditions during learning and rewarded performance is not reflected in the duration scores. Thus, on this showing, duration-score is not a sensitive measure for detecting the influence of these experimental conditions.

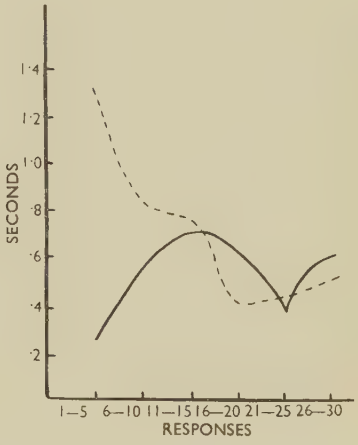
(*c*) The most significant changes in the standard deviation scores occur within the first 20 responses. This is also borne out by the coefficient of variation which

FIGURE 2.



Histogram of Response Duration Scores 1–15 (Means +)

FIGURE 3.



shifts from 75 per cent. to 60 per cent. This may be accounted for in the following manner: let us assume that the first lever responses were spaced, and separated by other activity, including trough exploration. Finding food has three immediately apparent effects: (i) the animal acts more vigorously; (ii) if the animal's food seeking activity has previously flagged, or given place to, for instance, escape behaviour, the food seeking behaviour regains its dominance; (iii) the likelihood of a repetiton of those actions (possibly accidental lever pressing) which preceded the finding of food, is considerably increased. The consistency of the change in the duration-scores of the first set of 30 responses may therefore be attributed to a period of "experimenting," leading gradually to the learning of relevant cues and appropriate actions. Some writers, notably Tolman and Krechevsky, would describe this behaviour in terms of changes in "hypotheses" as to "what leads to what." But this view does not take account of two distinguishable stages which may be described as, firstly, a period in which the individual learns that it has to perform a "ritual" before food is found in the trough; and, secondly, a period in which the "ritual" is perfected (technique or skill is developed). Only the former bears favourable comparison with the "formation of hypotheses," the setting up of "expectations" or "superstitions."

(*d*) In order to gain a more comprehensive view of the changes in the variability of the scores, a further analysis was carried out. The mean of the first 15 responses made by each animal was computed, and a frequency distribution drawn. The distribution has been reproduced in Figure 2. It strongly suggests a bimodal distribution, the modes falling between 0·20 to 0·29 seconds and 1·10 to 1·19 seconds respectively. If this histogram is considered in conjunction with the data displayed in Figure 1, it appears that there are two distinct populations: the initial duration

progressing from about 0·25 seconds in one case and 1·3 seconds in the other, to about 0·42 seconds between the 18th and 27th trials in both cases (Figure 3). This bimodality may be accounted for by the fact that the majority of animals encountered the lever in one of two ways: they were using the lever as a support for scaling the walls, or they hit the lever with the front paws whilst investigating the corner in which it had been mounted. In the former case, response-duration would be large, in the latter, small. However, the graph shows that irrespective of the initial "hypotheses" formed, the rats ultimately adopted similar modes of approach.

Response duration during unrewarded responding

Experimental extinction scores, i.e. measures obtained during a period when the customary reward has been withdrawn, have been extensively used to determine the degree to which learning had been accomplished under the conditions set up by the experimenter. Many writers have assumed that both the rate of responding (r) and the total number of responses made within an arbitrarily selected period (n) are the most representative forms of extinction scores, in that they act as reliable measures of the effects of such major determinants of behaviour as motivation and previous learning (Hull, 1943, 1951; Perin, 1942; Skinner, 1938). Skinner, for instance, has recently repeated his claim that "the rate of responding appears to be the only datum that varies significantly and in the expected direction under conditions which are relevant to the 'learning process'." (Skinner, 1948). But the results of our experiments suggest that these claims are excessive: both the rate of responding and the total number of responses made within a selected period of observation are very rough guides to the changes in behaviour occurring during unrewarded responding and to the changes which had occurred throughout the learning period.

(*a*) *Rate of responding:* Rate of responding may be directly and indirectly recorded. The former method requires a cumulative kymograph record to be made, from which the slope of the curve may be immediately computed (Skinner, 1938). The indirect method, on the other hand, has been favoured in experiments employing large groups of animals (Ellson, 1938; Williams, 1938). The time between the first and final response made within the session is divided into suitable units and the sum of the number of responses occurring within each period found.

The assumption underlying the indirect method is that the trend exhibited in the group curve is a *"generalized"* representation of the empirical data. It is sometimes assumed that the rate of responding is a continuous function of time (t) as, for example, in calculating reaction latencies, "str." This assumption obscures much interesting information in the data. As already noted, even in the earliest reports of the rat's lever pressing behaviour, it was remarked that unrewarded responding is spasmodic, rather than continuous, in character; that is, unrewarded responses occur in "bursts." However, except for occasional passing references, no attempt to analyse this phenomenon has so far been made. It is conceivable that these bursts of responses, or *response-groups*, follow a lawful pattern. Should this be the case, the analysis would be of considerable importance for the construction of curves, or the finding of mathematical functions, purporting to give a realistic description of the animal's behaviour. For instance, it would suggest the construction of two curves, one representing changes in the *rate of responding within* the *response-groups* (r_{RG}), the other describing the *rate at which response-groups emerge* (r_G).

(*b*) *Total number of unrewarded responses:* The total number of unrewarded responses (n) made by the animal within a set period represents the alternative method of measuring. In recent years it has become common practice to employ

a criterion of 4 to 5 minutes of no-response for terminating this phase of the experiment (Ellson, 1938; Koch, 1945; Perin, 1942; Saltzman and Koch, 1948; Williams, 1938). It follows from the considerations put forward earlier in this paper that this criterion fails to distinguish between the rate at which response-groups emerge as well as the rate of emittance of responses within each response-group. These two measures taken together may be more sensitive than the overall measure of "number of responses made to an extinction-criterion."

Moreover, it is notoriously difficult to obtain statistically significant differences between experimental groups in a Skinner-box when using "n." Even with large groups of animals, as in the Yale studies, the dispersion scores remain large. Furthermore, curves drawn from median and mean total scores frequently differ markedly from each other; different mathematical functions are needed for each and this is quite unpredictable, theoretically. The gross variability in the data may rest largely in the experimental techniques employed, and not in the experimental subjects.

It is possible to reduce the inconclusiveness of this type of data by eliminating fortuitous factors and by elaborating techniques of measurement. The latter is attempted in the next section.

(*c*) *Response-duration of unrewarded responses:* Table 2 presents the results of the second phase of the experiment (unrewarded responding). The medians of the *number* of unrewarded responses, "n," made by each of the experimental groups

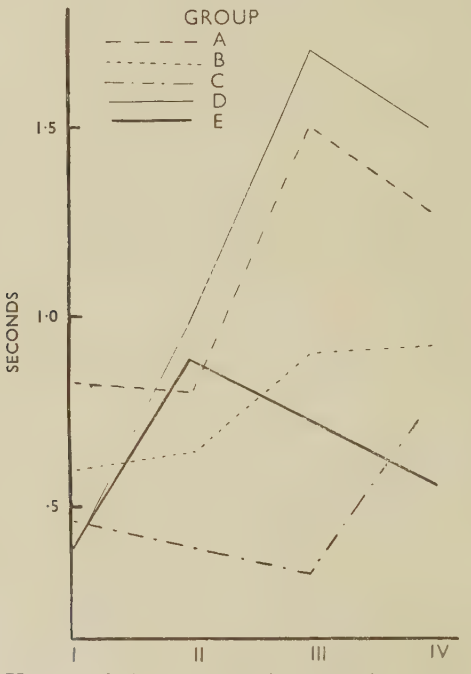
TABLE II

	I	*II* *Unrewarded responding*	
Group	*Average response duration*	*No. of unrewarded responses (medians)*	*Secondary reward conditions*
A	0·92	19	Source of secondary reward removed
B	0·78	32	0·5 seconds buzz
C	0·50	25	buzz for duration of response
D	1·20	25	0·5 seconds buzz
E	0·66	29	buzz for duration of response

shows the usual degree of dispersion (column II). The difference between the original conditions of training and those prevailing during unrewarded responding were not detectable by this measure. However, the existence of a discernable difference is shown by the results detailed in column I. Rats who obtained a buzz lasting 0·5 seconds for each unrewarded response (Group B and D) and those (Group A) for whom the source of secondary reward had been removed, all obtained high duration-scores. In the former, the sigma was 0·05, yielding a coefficient of variation of 10 per cent.—a remarkable consistency. The duration-scores for each of the five experimental groups are shown in Figure 4. Curves A and B are somewhat similar, as are curves B, C and E. In order to interpret these results we draw attention to the fact that both Group A and B have undergone a form of stimulus

deprivation—the former more so than the latter. The remaining groups responded under secondary reward conditions which were either the same as during rewarded responding or which involved an increase of such stimulation. However, despite the similarity in the form of the curves A and D, the origin of the two functions, 0·85 seconds and 0·42 seconds, respectively—a difference significant at the 1 per cent. level—suggests the possible operation of an additional factor. A hint, making the results more intelligible, comes from considering the course of the animal's learning. The task set involves that the animal press the lever, shuttle to the food trough, retrieve the pellet of food and having eaten it return to press the lever. During the

FIGURE 4.



Unrewarded Responses (grouped in units of 5)

early trials, however, a number of "abortive" lever-pressing responses occur, i.e. the lever is not sufficiently depressed to activate the food delivery mechanism and buzzer. Nevertheless, the animal shuttles to the food trough, goes unrewarded and promptly returns to make a more vigorous, extended lever-response which is accompanied by the buzz and followed by the customary reward. Thus, the vigorous, extended lever-responding observed during the second phase of the experiment had previously been rewarded as against "lethargic," "buzzerless" efforts. In the case of Group A this learning immediately manifested itself during unrewarded responding sessions. The view herein implied, that the animal is pressing the lever in order to get food *and* the buzz is supported by a test made after the completion of the main experiment. Group A was readmitted to the Skinner-box. The buzzer was connected to the lever, as for Group C, but the food magazine remained inactive. The response durations during this phase of the experiment were remarkably like those for Group B, C and D, except that the rate was more accelerated.

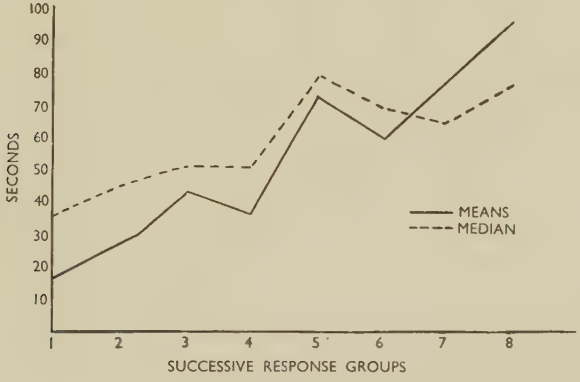
To conclude; the absence of the buzz accelerated the emergence of new behaviour patterns, such as more exaggerated lever-pressings. The results of Frick and Miller (1951) and unpublished results from our laboratory, on changes in the pattern of responding during rewarded and unrewarded trials, is relevant to the point raised here. It will be discussed in greater detail at a later date.

We furthermore predict that the duration-scores for the differing groups would attain the same upper limit if the unrewarded responding session would be extended to, say, an hour. The rate of approach to this upper limit, however, is dependent on distinctive secondary-reward conditions. It is apparent from this discussion of the changes in response-duration during both rewarded and unrewarded responding sessions, that more research must be done before the assumed relationships can be accommodated into systematic theory.

Response-groups

As already stated, unrewarded lever-responses occur in closely bunched groups. It must be left to subsequent research to investigate the specific properties of response-groups, and to determine the structural-functional properties of this phenomenon. The results here reported represent a first attempt to clarify some of the issues involved.

FIGURE 5.



(*a*) A criterion of 15 seconds between two consecutive lever-responses was selected in order to break down the data and isolate response-groups. The time intervals between response-groups, i.e. response-group latencies (t_o), were determined for all subjects and the mean and medians values found. The results are graphed in Figure 5. The intervals between the response-groups increase with the number of the response-group. These unrewarded responding sessions lasted until 4 minutes no lever-response. Subsequent studies have shown that in the type of Skinner-box employed in these experiments, a response recovery occurs shortly after the period laid down by this criterion.

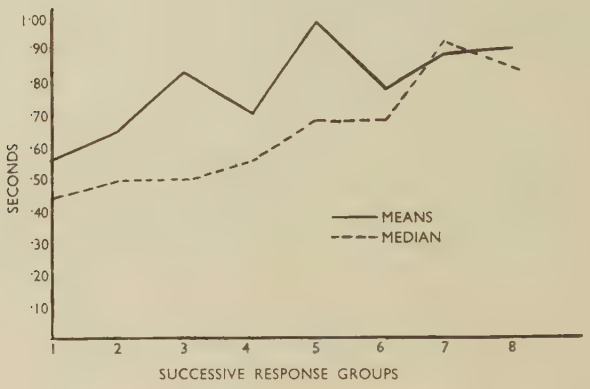
(*b*) It has previously been shown that the duration-scores increase as a positive function of the successive number of unrewarded responses made. In Figure 6, the mean and median duration-scores for response-groups have been plotted. It will be seen that the distribution of duration-scores become progressively less skewed,

i.e. the mean and medians are converging as a positive function of the order of response-groups. Three factors appear to determine this function:

(i) duration-scores within each response-group tend to increase;
(ii) the slope of the duration-curve tends to increase with successive groups;
(iii) the time-intercept value increases gradually with successive response-groups.

The specification of these three factors is tentative.

FIGURE 6.



(*c*) Finally, we draw attention to a number of problems concerning response-groupings which, in addition to those already considered in the preceding sections, require urgent investigation. These problems are:

(i) what factors affect the number of responses made in successive groups;
(ii) what factors affect the length of consecutive response-groups as measured by the interval between the first and final responses;
(iii) what factors affect the successive response-latencies in successive response-groups;
(iv) what is the relation between response-groups defined in terms of consecutive responses to the lever, or trough, as distinct from response patterns which involve making a series of heterogeneous responses.

IV

Summary

The present paper reports on an investigation of the factors determining changes in the lever-holding behaviour of rats in a Skinner-box. It was argued that the duration measure is sensitive to the following conditions:

(i) It is subject to systematic variation during the initial period of learning;
(ii) the variation decreases with increased practice (development of response-technique);
(iii) response-duration show a slight increase during extended rewarded practice, which may be related to the generation of fatigue, or a reduction in the motivation of the animal;
(iv) during unrewarded responding, response-duration increases. The rate of acceleration appears to be related to secondary reward conditions.

Stress has also been placed on the emergence during unrewarded responding of response-groups. Response-groups are defined as closely bunched, consecutive responses occurring within 15 seconds of one another. It was shown that respons-group latencies progress as a positive function of the number of response-groups. Furthermore, the following relations between response-groups and response-duration scores was indicated:

(i) the average response-duration for consecutive response-groups increases progressively;

(ii) the skewness in the response-duration distribution progressively decreases. This was due to an increase in the slope of the duration curve plotted for successive response-groups, with a corresponding increase in the value of the time-intercept for successive response-groups.

The author wishes to thank Mr. B. M. Foss and Mr. A. R. Jonckheere for invaluable advice in the preparation of this paper. Mr. John Whitfield kindly commented on the final draft and suggested several important changes in the presentation of the data.

The construction of the apparatus was made possible by a subsidy from the Central Research Fund, University of London. I am deeply indebted to Mr. L. Thomas for building the food delivery machine, and to Mr. R. Cohen for assistance in collecting the data.

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THE INFLUENCE OF PREVIOUS MOVEMENT AND POSTURE ON SUBSEQUENT POSTURE

BY

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An experiment with 21 subjects has confirmed the findings of other investigators that previous posture affects subsequent posture—the phenomenon of postural persistence. There seems also to be a tendency for the arm to be judged horizontal when in fact above the horizon, no matter which posture has been previously adopted—a "constant upwards effect." It has also been found that the direction of previous movement affects subsequent posture. After movement, an overshooting effect adds to a "constant upwards effect."

Various explanations of the phenomenon are discussed, and persistence is considered as an anomaly of postural recognition.

I

Introduction

The phenomenon of Postural Persistence has been described by Hoff and Schilder (1925), and studied in detail by Selling (1930). It consists in an unwitting deviation from, for example, the horizontal posture, when the subject attempts to bring his arm to the horizontal (in the absence of vision), after holding it in another posture for some time.

In the experiment of Hoff and Schilder the subject held his two arms horizontally in front of him, then raised one to 45° above the horizontal, keeping it there for about 30 seconds of "exposure." He then closed his eyes, and tried to bring the elevated arm to the same position as the other. In fact the arm remained somewhat raised.

Selling (1930) studied in 124 subjects the influences of duration of "exposure" time, of sex and of age and of which arm was tested for the phenomenon. He retained the two arm method, although Hoff and Schilder had pointed out that the effect could be obtained equally well if only one arm was used.

Dusser de Barenne (1934) expressed the opinion that the persistence was noticeably variable in any one subject, and did not occur in many individuals. He stated that voluntary activity could easily modify and obscure the phenomena, and it was therefore "not permissible to bring them into parallelism with the true brain-stem reflexes of Magnus."

Since postural persistence was to be studied in an experiment involving a conflict of visual and postural cues, it was decided to investigate the effect of previous posture on subsequent posture, in order to confirm Hoff and Schilder and Selling. It was also decided to investigate the effect of voluntary movement on the phenomenon.

II

Method

Small alloy clips were placed on the middle finger of each hand. These were shaped to form pointers which projected over the nail and about 5 mm. beyond the rounded end of the finger.

A point at the top of the right humerus was then chosen as the pivot point and proximal extremity of that arm. The determination was somewhat arbitrary, but sufficiently exact for the purpose. The lengths from this to the tip of the pointer (arm length), and to the floor (shoulder height) were then measured. It was assumed that these measurements were approximately the same on the left side.

The subject was then instructed: "You are to swing your arm five times completely round forward, and finish at the horizontal." This was demonstrated, and the subject told: "When you stop moving, you may correct the position of your arm as much as you like. This is not an exercise in correct stopping, but in judging the horizontal. Try to keep your fingers and arm straight all the time, and to come back to the same position at the end of every trial." The subject was asked to report any thoughts which might be relevant to the experiment. Ten trials with each arm were then undertaken, with the subject standing and blindfolded, in the sequence right, left, right, left, etc. (Action 1), the height of the pointer from the floor being noted after every judgment. The subject then rested for a short period and similar instructions were given to swing the arm backwards. The same procedure was followed (Action 2).

After a rest, the subject was told: "This time the procedure is somewhat different. You start with both arms folded. On the command 'Drop right,' you loosen your right arm and let it hang freely downwards. After five seconds, I will say 'Raise,' and you must bring the arm up to the horizontal." Having ascertained that the instructions had been understood, the experimenter continued, "We will try first the right, then the left as before. The arm which is not being tested in any particular trial may either be left folded, or also dropped to the side." Again ten trials of each arm were noted (Action 3).

After a rest, the subject was instructed: "This series is the same as the last except that, instead of dropping the arm freely downwards, you raise it to the vertical position. Thus, I will say 'Raise right,' and five seconds later '*Lower* to the horizontal.' " Again ten trials of each arm were undertaken (Action 4).

After another rest, the subject was instructed, "This time you also start with arms folded. When I say 'Extend Right,' stretch your arm forward in the horizontal position. After five seconds I will say 'Down and up.' You should then drop the arm freely downwards to the lowest position and *immediately* return it to the horizontal. Only the right arm will be tested." Ten trials were undertaken (Action 5). A further ten trials of the right arm only followed the instructions, "This series is exactly the same as the last except that, when your arm has been in the horizontal position for five seconds, I will say 'Up and down.' You should raise it to the vertical position and *immediately* return it to the horizontal." (Action 6).

A few subjects were also tested with trials of Actions 1 to 6 following each other in random order, the only sequence being left, right, left, but this procedure was very tedious and did not give rise to results different from those obtained by the other procedure.

III

Results

The results of 21 subjects were submitted to analysis of variance. The within-subject variance differed considerably from one subject to another; as might have been expected, some subjects were more consistent in their judgments than others.

In the first analysis, the results of all subjects ($N = 21$) in actions common to both arms were analysed. It was assumed that, when the marker placed on the finger tip was at shoulder-height (as defined above), the arm was horizontal. The height of the final judgment after deduction of the shoulder height was converted to the tangent of the angle which the arm made to the horizontal. In this way, differences of shoulder height and arm length from one individual to another were obviated. Since most deviations were upward from the horizontal, this direction was termed positive, and, for convenience, the tangents were multiplied by 1,000.

The means obtained in this way are shown in Table I below.

TABLE I

$N = 21$	*Mean deviations above horizontal (tangent units)*				
Actions	1	2	3	4	*Overall*
Left Arm	11·43	40·92	−12·39	30·25	17·55 } S.E.
Right Arm	19·75	67·83	12·40	41·11	35·27 } ±1·31
Mean	15·59	54·37	0·01	35·68	26·41 } S.E. ±0·93
	S.E. ±1·86				

S.E. of Entries in the Body of the Table = ±2·63.

The within-subject differences were so great, that before drawing conclusions from Table I, it was decided to test all effects against their interactions with subjects.

Following this, it was found that the effects left arm × right arm, and arms × actions were significant at only P = 0·05, and Action 1 × Action 2 and Action 3 × Action 4 at P = 0·01.

The barely significant arm × arm effect accords with Selling's results. He reported that more persistence was shown by the left arms of right-handed subjects. Of our 21 subjects only one man was left-handed, and two others were partly right-handed, probably shifted sinistrals. The remainder were fully right-handed.

Table I shows that, after exposure downwards (Action 3), the left arm judgments were below those of the right arm. On the other hand, after exposure upwards, judgments of the left arm were not above those of the right. In Action 3 only the left arm finished *below the horizontal*.

TABLE II

	Mean deviation above horizontal					*S.E. of individual means*
Actions	1	2	3	4	*Overall*	
Male N = 13	4·81	62·96	1·65	28·89	24·58 S.E. ±1·18	±2·36
Female N = 8	33·11	40·41	−2·67	46·69	29·39 S.E. ±1·15	±3·01

The overall means showed no significant sex differences (Table II) but there was a suggestion that the judgments of women were influenced less by previous movement than were those of men, and more by previous posture. After taking out the subjects, arms, and actions effects, there remained a residual of the total variance indicating variations between trials within runs of ten. This revealed no practice nor cumulative effects. As a further check against cumulative effects several subjects were tested with trials of the different series and arms fully randomized. No such effects were found.

In the second analysis, the results of all subjects (N = 21) in actions common to the *right arm only* were analysed, the means being obtained in the same way as in the first analysis. Table III shows that there were no overall sex effects and normal postural persistence is again apparent (Actions 3 and 4).

TABLE III

	Mean deviation above horizontal					*S.E. of individual means*
Action	3	4	5	6	*Overall*	
Male N = 13	12·48	35·28	66·25	37·31	37·83 S.E. ±1·54	±3·08
Female N = 8	12·26	50·58	75·61	36·85	43·82 S.E. ±1·96	±3·93
Means N = 21	12·40	41·11	69·82	37·13	40·11 S.E. ±1·21	
	S.E. ± 2·42					

It might be expected that "exposure" at a horizontal position (Actions 5 and 6) would result in a final judgment midway between those of Actions 3 and 4. The figures did not confirm this except in the case of women in Action 6.

The overshooting of the true value on raising to the horizontal in Action 5 is comparable to that in Action 2 (swinging backwards), except that men were more subject to the effect in Action 2, and women in Action 5.

The subjects × subjects, subjects × actions, actions × actions, and sex × actions interactions were all significant even when tested against the residual term (P = 0·01), and the actions effect remained significant (at P = 0·01) when tested against the subjects × actions effect.

TABLE IV

Question	*Answer*	
1. How is horizontal judged?	(*a*) Felt to be horizontal	8
	(*b*) Feeling—relation to shoulder ..	2
	(*c*) Feeling—relation to trunk	2
	(*d*) Feeling—undefined	1
	(*e*) By visual imagery	2
2. How are you sure that arm is horizontal?	(*a*) Felt to be horizontal	4
	(*b*) Feeling—relation to shoulder ..	2
	(*c*) By visual imagery	1
	(*d*) By returning to same position ..	1
	(*e*) By moving back same distance ..	1

In the third analysis, the results of subjects 11 to 21 only were analysed, the right arm alone being considered, and only the results of Actions 5 and 6. It will be remembered that both the initial (exposure) values of the horizontal and the

final judgments of these subjects were measured, since it was thought that the initial value might have influenced the final. This was found to be so. The regression of the final value on the initial was very highly significant (regression coefficient = 0·574; S.D. = 0·059). Even after adjustment for this regression, the effects of subjects and actions with their various interactions were still highly significant, but there was no sex effect before or after adjustment. Thus the different effects of the movements upwards and downwards from an approximately horizontal exposure were not only due to variations in this initial exposure position, but were also a result of the movements.

From questions asked after the experiment, it was apparent that most subjects judged the horizontal by "knowing how the arm feels when horizontal." Table IV summarizes the answers to the questions.

IV

Discussion

Selling's results were confirmed, in that it was shown that a previous posture lasting for as little as five seconds influenced subsequent posture.

Since most of our subjects were right-handed, and since the normal effect of postural persistence was somewhat more evident in the left arm than in the right (although in fact the differences were not significant at more than P = 0·05), Selling's conclusions on the effect of handedness were on the whole confirmed.

However, in our Action 3 (arm exposed downwards), judgments of the horizontal by the right arm were *above* horizontal (Table I) which is a reverse tendency.

It is not clear whether Selling found this reverse tendency, since he mentioned no plus nor minus values. If he did not, then Table V compares his results with those of our experiment converted to angles.

TABLE V

5 *secs. exposure*	*Selling*	*Present experiment*
Ages	18–23	20–30
N	48	21
Right Up	+1·32 deg.	+2·33 deg.
Left Up	+2·02 deg.	+1·75 deg.
Right down ..	−1·27 deg.	+0·70 deg.
Left down.. ..	−1·88 deg.	−0·70 deg.

It will be noted that the age range of our subjects was greater, though their number was less. However, whereas our angles were calculated according to the arm length of every individual separately, those of Selling were obtained from the average lengths of his two sex groups. Also Selling's subjects exposed at 45° from the horizontal, and their arms were held in that position during exposure, whereas ours exposed at 90° with free arms.

Bearing in mind these differences in procedure, the two sets of results would not seem to disagree, with the exception of our anomalous right-down value.

In Actions 1 and 2, the arm was held in the lowest (vertically downwards) position and then swung five times. The swings lasted from 3 to 7 seconds with individual differences. One might therefore expect a reasonably constant posture, influenced by the initial downwards position, since postural persistence has been shown to persist up to 60 seconds (Eidelberg [1926] quoted by Selling p. 6). However, Tables I and II showed that in both actions the final judgment was *above* the horizontal for both arms and both sexes, and that the magnitude of the upwards deviation was greater in Action 2 (swinging backwards). Thus the direction of swinging had a marked influence on the final horizontal.

It might be supposed that the final scores of Actions 1 and 2 were the result of a "constant upwards effect" summing with the movement effect of overshooting. The data also agree with Sandstrom's (1951) conclusion that men tend to point below eye level, and women to eye level.

From the introspective evidence summarized in Table IV, it appears that most subjects determined the horizontal when blindfolded by "knowing how their arms feel when horizontal." The consistency with which individuals judged the horizontal varied considerably, but the subjective awareness of "how the arm feels when horizontal" was not much divergent from the objective posture (initial values Actions 5 and 6), unless the arm had previously been held in an "exposure" posture which differed markedly from the horizontal.

Since most experiments on Postural Persistence have centred round the horizontal posture, it might be thought that the phenomenon resulted from poor judgment of this arbitrary position. However, the effect of persistence can be shown, it seems, from any posture to any other posture. Also, if a mark is made anywhere up a wall within arm's reach, and the arm is hidden by a screen, it will be found that the arm can be brought opposite this mark fairly accurately, even though there is no sight of the arm to give visual "feed-back." If, however, the arm has been previously "exposed," the usual postural persistence effect ensues.

Thus our experiment has confirmed that previous posture influences subsequent posture, and has shown that movements of long duration influence subsequent posture in the direction of overshooting, while movements of short duration have a lesser effect, the previous posture again assuming importance.

In previous studies, three explanations of this phenomenon have been offered. It was thought to be due: (1) to "persistence of muscular tension and innervation" (presumably as a result of central after-discharge); (2) to "sensory adaptation"; or (3) to the characteristics of "a central apparatus."

The first explanation was rejected by Hoff and Schilder on the grounds that, if the "exposure" was below the horizontal, the final judgment was also below the horizontal, and that persistence is apparent even when the arm is relaxed. In addition, to maintain a horizontal arm posture apparently requires more "muscular tension and innervation" than to maintain other arm postures for an equal time. Also Hick (1953) found that similar phenomena were much affected by psychological factors, and concluded that they were not due solely to physiological after-discharge.

The second explanation was favoured by Hoff and Schilder (1925) and by Hick (1953), who studied aftercontractions of a similar nature and concluded that there must be a process counteracting sensory adaptation "otherwise a voluntary isometric contraction intended to be of constant force would steadily increase." The process postulated though "initially equal to that of sensory adaptation declines more rapidly in time," and "is the recovery from that which is felt as fatigue." He remarks that "sensory adaptation . . . is something we have to live with, and learn to allow for, as far as possible," and concludes that "information from less-adapted

or more quickly recovering sense organs would be available" to compensate partially for the effect of sensory adaptation.

Thus Hick has adopted the view that the phenomena result primarily from the properties of the nervous receptors involved, and has suggested how this may be reconciled with his finding that "after-contraction is . . . strongly affected by psychological factors" (1953, p. 169).

The third explanation, in terms of "a central apparatus" was adopted by Hoff and Schilder. The nature of this was not specified, but it was probably similar in conception to Head's (1911) Postural Schema, which has survived many attempts at clarification.

The present writer visualises a comparison (more or less conscious depending on the individual) being made between the total sensory input at the moment and the stored past impressions of "how the arm feels when horizontal" (Table IV). The latter aspect seems to deserve more emphasis than was given to it by Hick.

After "exposure," sensory adaptation (and perhaps fatigue) alter the total input stream of afferent impulses from the arm. The altered stream then "matches" with whatever neuronal processes underlie awareness of "how the arm feels when horizontal," when in fact the objective posture is incorrect.

In this way, postural persistence may be regarded as an *illusion* in the posturo-kinesthetic sense-modality, or as a normally occurring *anomaly* of postural recognition.

A more detailed explanatory hypothesis must evidently await advances in our understanding of the operation of the many different types of sensory receptors involved, of the neurophysiology of fatigue, and of awareness of posture generally.

The author is grateful to Professor G. Humphrey for permission to carry out the work, and to Dr. M. R. Sampford for statistical help. He was working with a grant from the Medical Research Council,

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AN EXPERIMENT WITH OCCASIONAL FALSE INFORMATION

BY

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An experiment is described in which subjects were presented, under one condition, with advance information of doubtful value. The evidence suggests that advance information was accepted, although the uncertainty created had a detrimental effect on the subjects' performance.

I

Introduction

In an earlier paper on advance information in sensori-motor skills (Leonard 1953) "receptor-effector" anticipation was defined and its role discussed. The present paper is a sequel.

The work was carried out with the stylus apparatus described in the earlier paper. With this apparatus subjects could be given information either at or before a common action point. It consisted of a five light display and a control panel with five discs flush with the plywood forming a pentagon corresponding to the display. There was one disc in the centre of the control panel, and subjects had to slide a stylus between this centre disc and an outer one according to the state of the display In condition (1) the display changed when the centre disc was touched, the indicated disc having been touched first; in condition (2) the display changed when the indicated disc was touched, the centre disc having been touched first. Thus for each response both indicated disc and centre disc had to be touched, but whilst in the first condition subjects could not know what to do beyond the centre disc until they actually got there, this information was provided in advance, i.e. at the indicated disc, in the second condition. In this condition therefore subjects could know all the time what to do next; on leaving the centre disc for the then indicated disc they knew that they would have to return to the centre disc and on reaching the indicated disc they were given the information concerning activity beyond the centre disc. There was thus something like "continued certainty." It was pointed out in the preceding paper that in the condition where information was given only at the centre disc, the point of action as it were, there had to be something of a hiatus in the flow of definite information. But under both conditions used, whenver information was presented, it could always be relied upon in the sense that a disc once indicated would remain "correct" until touched. This is of course an assumption which always has to be made whenever a response is initiated.

It has been known for some time that with simple responses there is a period of about 0·12 seconds after the initiation of a response during which the response can no longer be checked. If the display changes during this period, we may be aware of this change, but we can do nothing to arrest the movement (Guenther, 1911, Bates and Hugh Jones, 1944). The results of the stylus experiment reported in the previous paper suggested that subjects in condition (2) had initiated the appropriate activity for the stage beyond the centre-disc before reaching the centre disc. Pushing the argument a little further, we might say that they had accepted the advance information and were acting upon it in the firm "knowledge" that their action would still be appropriate. It seemed interesting to find out what would happen when the conditions no longer provided an adequate basis for firm knowledge, i.e. when the

display was, in fact, liable to change again when subjects got to the centre disc and the new and not the old display would have to be responded to. The question now was: if information given ahead of the point of action has a measure of uncertainty attached to it, will it still be accepted?

II

Methods and Procedure

Apparatus

The stylus apparatus has been described in the earlier paper (Leonard 1953). In the present experiment sequences of 50 stimuli only were used. An additional bank on the uniselector was used to provide occasional contacts in parallel with existing stimulus positions. When a subject touched the centre disc at a time such a contact was reached in the series, a relay changed the display by switching over from the currently used bank to yet another bank. The relay would be held until the next correct response returned it to its resting state and the main bank came back into use. The second display change therefore was not produced in the same manner by the apparatus as in conditions (1) and (2). The apparatus latency can reasonably be assumed to have been very slightly shorter, if anything, in the former case. It was necessary in this experiment to introduce an additional auditory error indicator in the form of a single stroke on a bell. Pilot runs had shown that subjects otherwise might not be aware at all of the second display change before they had reached the disc originally indicated but now incorrect, their indication of correctness of response being in fact that the display had changed. Usually one experience of the bell per trial was enough to draw attention to the risk involved.

Conditions

The experiment was given under three conditions: the first two have already been described in the introduction. In condition 2a the display would *always* change when the subjects touched the indicated disc, having first touched the centre disc, but *sometimes* (see Table II) it would change again when the subject touched the centre disc. These occasional changes were spaced at random through the trial, and were never entirely in the same order for successive trials.

Procedure

Table I shows the experimental plan. The two groups of three subjects each were not matched.

TABLE I

Experimental Plan

Day		1								2					
	Trial	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Group I	Condition	1	2	1	2	1	2	1	2	2a	2a	2a	2a	1	2
Group II		2	1	2	1	2	1	2	1	2a	2a	2a	2a	2	1

In all, subjects were given fourteen trials of 50 responses each on two successive days. They had the control-display relationship explained to them, were asked never to lift the stylus off the panel, and were told that their task was to make 50 correct responses in as little time as possible, making as few errors as possible. They were told that the apparatus would cut off when they had completed a trial. Possible errors were demonstrated and subjects were allowed to make a few practice moves before the first trial (mainly to show the experimenter that the instructions had been understood). They were not given any specific instructions on how to do the task. The subjects were told after each trial how much time they had taken. Apart from these general instructions there were specific instructions for the three conditions, given to each subject before he

was first exposed to them: (1) "Starting from the centre slide the stylus to the indicated disc and come back when one of the other four lights will come on. Only one lamp will be on at any one time." (2) "Starting from the centre disc slide the stylus to the indicated disc when one of the other four lights will come on. You must touch the centre disc before going on to the next indicated disc. Only one lamp will be on at any one time." Before their first experience of condition (2a) subjects were told that this was similar to condition 2 in that the display would always change when the indicated disc was touched, but that sometimes the display would change again when they touched the centre disc.

They were told that if the display changed again they would have to touch the now indicated disc. They did not know how many changes there would be, nor when they would occur in any one trial.

From a technical point of view it would have been possible to effect display changes at the centre on 28 occasions. A smaller number (see Table II) was eventually chosen because this enabled the experimenter to change the positions of these changes between trials.

It seemed advisable to vary the number as well as the position within the sequence at which secondary display changes could occur, in order to prevent subjects from learning to expect them.

Scoring was carried out in terms of total time, for all trials, to the nearest $\frac{1}{2}$ sec.; and times for two components making up one response. (It will be appreciated that particularly under condition (2a) performance tended to be rather erratic so that the more detailed recording possible in the experiment reported earlier was no longer meaningful). The two components scored were (1) the time between touching the indicated disc and reaching the centre disc (EP & In), and (2) the time between touching the centre disc and reaching the indicated disc (C & Out). Those C & Out components of condition (2a), at the beginning of which there was no display change, were called "*unaffected*"; those at the beginning of which the display did change were called "*affected*." Readings were taken to the nearest 0·025 sec. and only the 12th, 13th and 14th trials of each subject were scored in detail.

III

Results

TABLE II

Mean Times in Seconds per Trial for 6 Subjects

Trials	7/8	9	10	11	12	13/14
Condition						
1	46·2					44·9
2	38·6					36·2
2a		53·9	49·2	46·4	48·0	
Additional Display Changes		(17)	(17)	(12)	(16)	

Table II shows the composite final training scores for the 7th and 8th trials of conditions (1) and (2), the four trials under condition (2a), and the composite scores for the 13th and 14th trials under conditions (1) and (2). It should be noted that there was a marked slowing up on the first trial under condition (2a), the group settling down eventually to something near the level of performance under condition (1). The dip on the 11th trial was presumably due to the fact that there were fewer occasional changes in this trial than in the others.

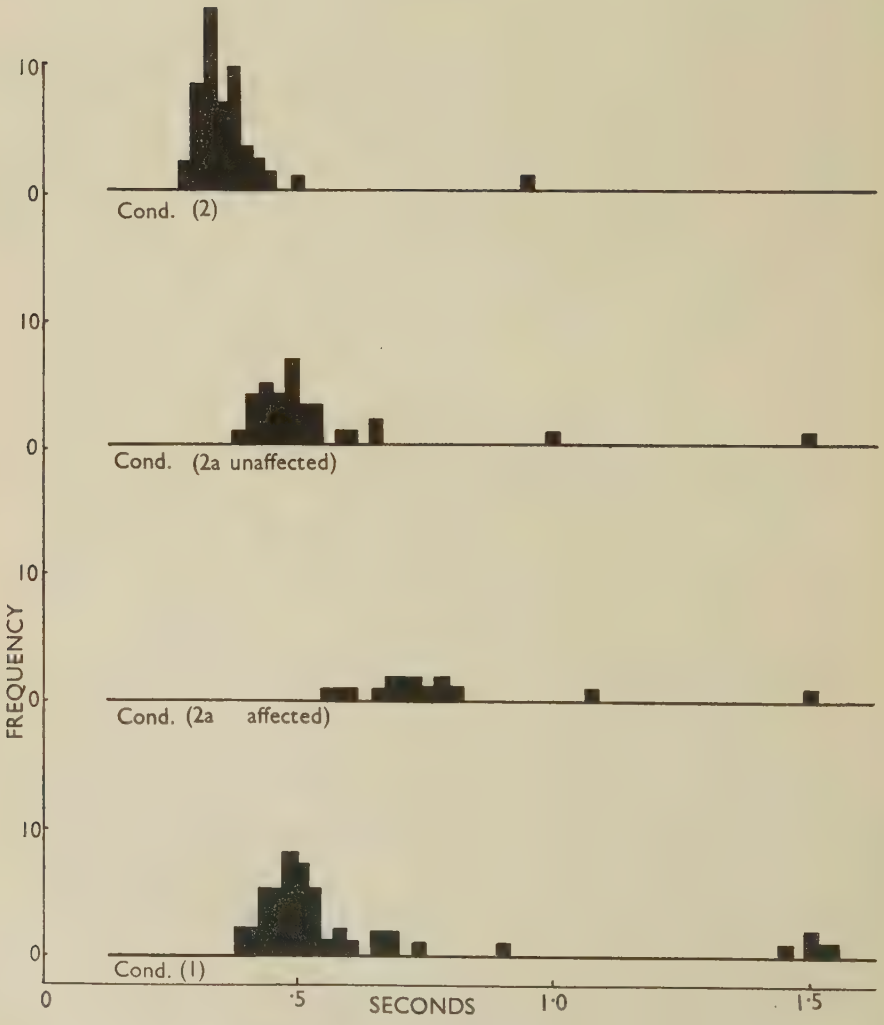
Component times were obtained for the 12th, 13th and 14th trials of each subject. The group means shown in Table III were obtained after excluding some very large readings which would have exaggerated the trends found. There were about 2 or

TABLE III

MEAN TIME IN SECONDS FOR THE TWO COMPONENTS PER RESPONSE IN TRIALS 12, 13/14

Condition		*C & Out*	*EP & In*
1		0·57	0·27
2		0·39	0·28
	unaffected	0·51	
2a			0·29
	affected	0·73	

FIGURE 1.



(C & Out) Distributions of one subject in main experiment

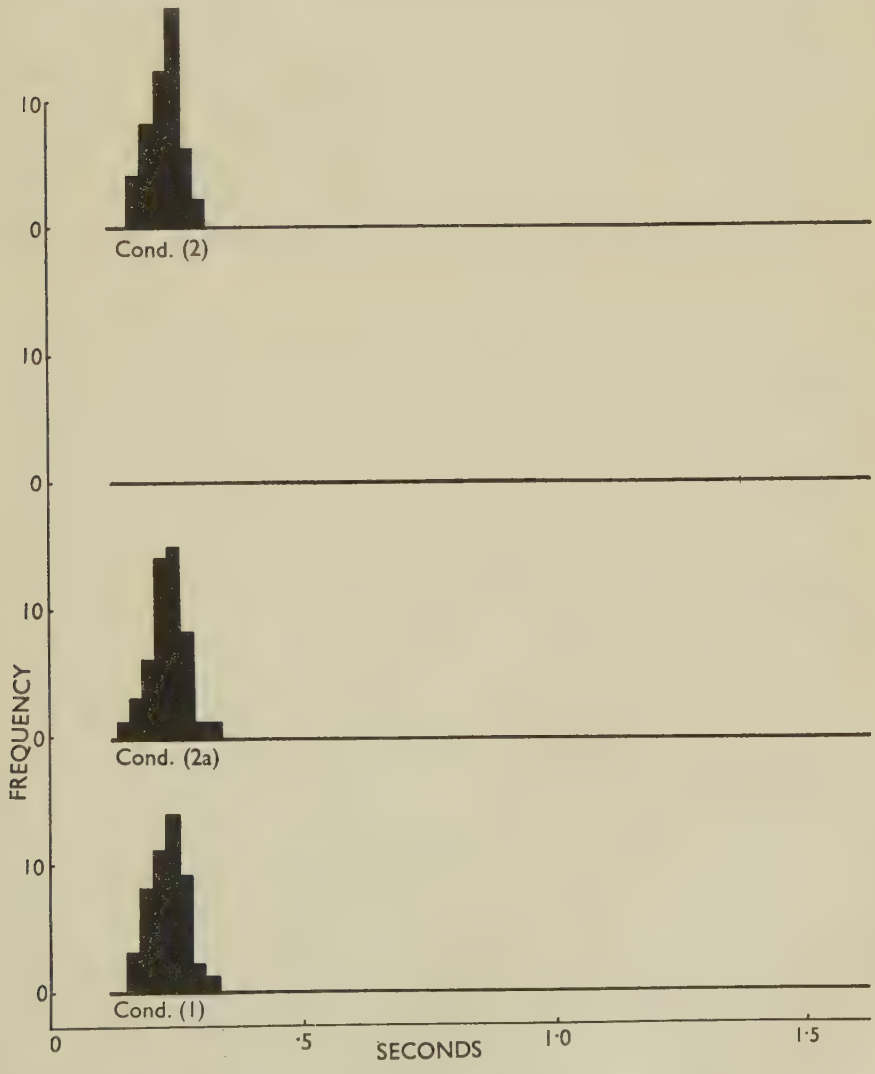
3 of these readings per distribution. A transformation to logarithms did not seem indicated.

The relationship between the three EP & In group means was not reflected in individual subjects' means and no consistent trend was noted in the three EP & In distributions for each subject. In the discussion below the C & Out components will be considered, neglecting differences between the other component.

The relationship between the group means obtained for the four C & Out components was reflected in all subjects. Similarly, the six sets of distribution showed the same general pattern.

A typical set of C & Out and EP & In distributions for one subject is shown on Figures 1 and 1a.

FIGURE 1a.



(EP & In) Distributions for one subject in main experiment

IV

Discussion

By instruction, subjects had to make 50 correct responses per trial in as little time as possible. In condition (2a) where the display changed again at the centre, they had at least two ways of complying with the instructions: They could either respond to the display only when they reached the centre disc; for the light which was on then would always be "correct." In other words they could respond as in condition (1). It was thought that subjects might eventually adopt this method, particularly since the occasional changes of display at the centre tended to impose a motor pattern more like that found in condition (1). Alternatively they could respond when reaching the indicated disc although on some occasions the light to which they had responded might turn out to be not correct. That is to say they could perform as in condition (2) risking however occasionally having to modify responses already initiated.

Considering the effects on the C & Out components one may compare the two expectations and the observed results in the following manner:

Expectation I	affected (2a)	$=$ non-affected (2a) $=$ (1)
Result	affected (2a)	$>$ non-affected (2a) $\approx$ (1)
Expectation II	affected (2a)	$>$ non-affected (2a) $=$ (2)
Result	affected (2a)	$>$ non-affected (2a) $>$ (2) $\approx$ (1)

One is therefore faced with the somewhat confusing situation that both expectations are partially fulfilled. This leads to an apparent contradiction. The fact that the non-affected components in condition (2a), i.e. when the display had not changed again at the centre, are similar to those in condition (1) suggests that information was accepted only at the centre disc in condition (2a). In this case a display change at the centre should however not have had any effect on the affected components. The fact that the affected components' distributions were always clearly separated from the non-affected components' distributions suggests that the display-change at the centre did have an effect. This in turn suggests that subjects had accepted information when it was presented at the indicated disc and had to re-organize their response when the display changed again at the centre.

But if in condition (2a) subjects did accept information at the indicated disc, why were the values for the non-affected components of that condition comparable to those of condition (1) rather than of condition (2)?

There seem to be two possible answers, and one cannot be certain whether these may not really be identical. It may be that subjects accepted information at the indicated disc but required confirmation at the centre-disc. Or it may be that the higher value of the non-affected components in condition (2a) reflects the need to watch the display more carefully and continuously in this condition. Both these answers suggest that the introduction of occasional additional display changes created a greater over-all uncertainty. If this contention is correct the numerical similarity between the values for the unaffected components of condition (2a) and those of condition (1) may be spurious, i.e. the values may reflect different operations.

There were therefore two effects which made performance under condition (2a) slower than under condition (2): a direct effect resulting from the actual additional display changes; and an indirect effect resulting from the greater over-all uncertainty.

On the whole the experimenter's observation of subjects' performance tended to be in line with the data obtained from the records. Subjects were clearly trying to maintain in condition (2a) the smoothness possible in condition (2). Far from opting to stop at the centre for every response they seemed to learn how to modify responses on the way to the previously indicated disc.

After the experiment it was suggested to each subject that it might perhaps have been more reasonable to perform in condition (2a) as in condition (1) and thus avoid the need to modify initiated responses. They did not think this a good idea. Neither did others to whom the experiment was demonstrated and who tried it out. It was possible deliberately to adopt the method of conditon (1) but it was not easy, and certainly not the spontaneous method adopted.

Subsidiary experiments carried out with different proportions of additional display changes, or subjects having condition (2a) without previous epxerience of the other two conditions bore out the main findings presented here.

The question asked in the introduction was: if the information given ahead of the point of action has itself a measure of uncertainty attached to it, will it be accepted? The evidence suggests that it was accepted, but that the efficiency with which it was used was reduced. This reduction in efficiency may reflect the greater uncertainty inherent in the task. It could also be due to the need to pay more attention to the display. In this particular setting—where of course making an error did not have very drastic consequences—subjects did seem to accept advance information even when it was of doubtful value.

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THE PERCEPTION OF SHORT PHRASES PRESENTED SIMULTANEOUSLY FOR VISUAL & AUDITORY RECEPTION

BY

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Subjects were provided with outline maps that were incomplete in several details. Brief, simultaneous, visual and auditory instructions were given for completing some of the missing details. Certain items could be completed on the basis of direct information contained in one or other of the sensory modalities. Others, however, could be completed only because of their relation to details capable of location by direct instruction. Information important for the completion of map details was distributed randomly among short passages of unconnected words. All relevant visual and aural clues were presented simultaneously in every case. Opportunities for alternations of attention were curtailed.

Thirty-six subjects were randomly assigned to three experimental conditions, and to two groups that were given different instructions. One group was told that relevant information would always appear simultaneously, while the other group was not allowed this information.

The number of successfully located simultaneous pairs of items presented for direct location was found to be no greater than could be expected by chance. The total number of correctly located items was less than 50 per cent of the possible items. There was no difference in the number of correctly located simultaneous pairs of items between the "instructed" and the "uninstructed" groups. The "uninstructed" group did not learn in the course of the experiment that all relevant material was presented simultaneously. Significantly more correct completions were made with the visual material than with the auditory. It is concluded that successful division of attention did not occur.

I

Introduction

Recently, Hebb (1949), in proposing a new orientation to the problem of the organization of behaviour, touched briefly on the age-old argument concerning the division of attention. He adopted the position that attention may often be of a multiple nature since there is little, if any, evidence to support the commonly held view that attention to two things that are not organizable into a single unit is impossible. However, recently Mowbray (1953) has provided some data that, while not completely conclusive, do argue in favour of the unitary nature of attention.

Two main criticisms may be inveighed against this research. The method of visual presentation, while curtailing to a considerable extent the opportunities for alternations of attention, did not entirely eradicate them. The second objection concerns the nature of the experimental material. Prose selections were used, and they were of considerable length (154 -220 words) so that the performance decrement exhibited from non-simultaneous to simultaneous presentation may have been as much a function of forgetting, owing to some interference between the two streams of conflicting stimuli, as it was an initial failure to perceive.

Purpose of experiment. Therefore, it was considered advisable to construct an experiment that would make use of brief verbal messages, with different auditory and visual messages presented simultaneously, and would in so far as possible prevent rapid alternation between sensory modalities. Accordingly, an experiment was designed that made use of brief verbal messages leading to a simple map-completion

test. The verbal redundancy of the instructions was reduced to a minimum, and their brevity served to keep them within normal memory span.

II

Experimental Method

Material. Seven coloured outline maps were traced on sheets of translucent drawing parchment about 22 in. long and 14 in. wide. The details on each map consisted of lakes (blue), towns (cross-hatched red lines), parks (green), highways (red), and groups of buildings (purple squares and rectangles). Very near to each detail a small rectangular cut-out was made in the maps as though a name had been deleted. Transparent plastic sheets of the same size were cut, and small rectangular holes corresponding in size and position to the cut-outs in the maps were made. The plastic sheets served to cover the maps and protect them from accidental marking and tearing.

Visual instructions for the location of the details on the maps were typed on a roll of recording paper 6 in. wide. A thyratron-driven motor pulled the tape past a viewing window cut in a grey-coloured, metal screen. The width of the viewing window was the same as the width of one line of type and its length enough to allow vision of the entire width of the recording tape. The lines of type were horizontal, but the viewing slit was slightly tilted down at the right. Thus only one of the four widely separated, but evenly spaced, words on each line could be seen at a time.

All names given to map details were one of ten colours (rose, blue, black, red, yellow, green, orange, purple, brown, or aqua), and no colour was used more than once for any detail on a given map. Information for the location of a detail was given in terms of alphabetical and numerical map co-ordinates. Thus, for instance, one of the towns on a map might be located from the following instructions: "Yellowtown at A-Seventeen."

There were six, eight, or ten details to be located on any one map depending on the condition being used in the test. The three test conditions utilized were as follows:

Condition I. There were six items to be located. Four of these could be located on the basis of direct information, i.e. they were associated with map co-ordinates, while the other two could be located only indirectly with reference to the location of the direct items. No co-ordinates were provided for these latter. The four details about which co-ordinate information was supplied consisted of two pairs of simultaneously presented items. Of each pair, one item was given visually and the other aurally.

Condition II. There were eight items to be located. Six of these could be located from information given in the form of map co-ordinates. The other two could be located indirectly as in Condition I. The six details about which co-ordinate information was supplied consisted of three pairs of simultaneously presented items. Each pair consisted of one visual and one auditory presentation.

Condition III. There were ten items to be located. Eight of these could be located from information given in the form of map co-ordinates. The other two could be located indirectly as in Conditions I and II. The eight details about which co-ordinate information was supplied consisted of four pairs of simultaneously presented items. As above, each pair consisted of one visual and one auditory presentation.

For every item that had to be located, there were on the map at least four possible correct answers considered from the standpoint of chance. That is to say, if there was one lake to be located, there was a total of four lakes on the map that could be the correct one. Likewise, if there were two lakes to be located, then there was a total of eight lakes on the map.

All of the information necessary for completing the required parts of a map was presented in four sections, but only a small proportion of any of the four sections was relevant to the task at hand. The remainder was unconnected words, similar in some ways to the key phrases, but making no sense overall. The length of each section ranged randomly from 24 to 44 words, and the relevant information was positioned by chance within a given section. A single section never contained more than two relevant items. Sometimes only one item was relevant, and for some of the conditions, entire sections contained no relevant information at all.

The auditory material was recorded on a magnetic tape recorder by a female voice, and was organized identically as described above. Overall synchronization of visual and auditory presentations was accomplished by careful timing and recording so that there was very nearly a word-for-word correspondence between the two channels. In all

sections the relevant visual and auditory phrases coincided temporally, and were of exactly the same length.

The speed of visual and aural presentation was approximately 106 words per minute. For normal reading this is an extremely slow speed, but it will be remembered that there were but four words to a 6-in. line necessitating unusually large eye-movements.

Procedure. The subjects were seated facing the visual pacer, while to their left was the auditory tape recorder, and to their right was a map-board holding the experimental map. They were given a sheet of typed instructions to read, and were told to take all the time they needed to understand them.

Following the reading of these very detailed directions, a few further instructions were given to emphasize some of the more important aspects of the experiment. The subjects were informed that the information would be given in four sections, but they were not told how many relevant items they were to expect in any given portion. They were told that some sections might not contain anything of use to them in their completions. They were then instructed that the auditory and visual displays would be halted at the end of each of the four sections to allow them to complete whatever details they could. They were asked not to attempt completions before the end of a section. Paper and pencil were provided to allow them to make any notations they desired during or after the presentation of any section. They were encouraged to guess at the locations if they had any reasonable basis for doing so, but were allowed only one guess for any one detail.

The subjects were given seven cards—one for each of the two practice maps and the five experimental maps—on which were printed the names of all of the items to be located on each map. They were allowed to keep the appropriate card available for reference throughout the entire experiment. Each map was an entity in itself and completely independent of every other.

Before beginning the experiment, one-half of all subjects were further instructed that all relevant pieces of visual and auditory information would appear simultaneously, and that there would *never* be any useful information in one channel without there also being at the same time some equally useful but different information in the other. This group was termed the "instructed" group. The other half of the subjects were not informed of this detail and hence were termed the "uninstructed" group.

Following this lengthy and involved briefing, the two practice maps were completed, during which time all misunderstandings and misapprehensions were cleared up. Responses were made, through cut-outs in the maps and covering plastic sheets, on to paper inserted under the maps.

The experiment was completed in a single session requiring about 1 hr. and 15 min. in all—including instructions, practice, and test maps.

At the end of the experiment all subjects in the "uninstructed" group were asked the following question: "What can you tell me about the presentation of the relevant items of information that appeared in the visual and auditory series?" If they did not reply that the relevant bits had appeared simultaneously in both channels, they were then asked specifically if they knew that such had been the case in every instance, and their replies were recorded.

Subjects. A total of 36 subjects was assigned at random to one or other of the three conditions and to the "instructed" or the "uninstructed" group. They were university undergraduates, graduate students, scientific research workers, and a few others participating to a large extent in university life. They ranged in age from 19 to 36 years.

III

Results and Discussion

In considering the results, the total emphasis will be placed on those items about which direct information was supplied. Those items that could be located only with reference to the position of directly given ones were originally included in the experiment to provide supplementary information in case simultaneous reception proved possible. As will be shown subsequently, their only function was to provide two additional guesses per map in the experimental situation.

Simultaneous pairs. Since the major purpose of this experiment was to determine whether simultaneous auditory and visual receipt of information could occur, the

first analysis will be concerned with the number of times that both the visual and auditory items of a simultaneous pair were correctly perceived. If simultaneous reception of information is impossible, no pairs should have been perceived except as the result of chance guessing.

Table I shows the number of successful completions of both of a pair of items presented simultaneously for direct location. The results are tabulated for the three

TABLE I

SUCCESSFUL COMPLETIONS OF BOTH OF A PAIR OF ITEMS PRESENTED SIMULTANEOUSLY FOR DIRECT LOCATION

	Experimental condition			
	I	*II*	*III*	*Total*
"Instructed" group				
Number	5	17	12	34
Possible	60	90	120	270
Per cent.	8·3	18·9	10·0	12·2
"Uninstructed" group				
Number	9	8	12	29
Possible	60	90	120	270
Per cent.	15·0	8·9	10·0	10·7

conditions and for the two groups ("instructed" *vs.* "uninstructed"). The extreme right-hand column gives the total pairs summed over the conditions. An analysis of variance was performed on the data from which this Table was compiled. The results are given in Table II where it can be seen that neither the instruction given to subjects nor the experimental conditions contributed any significant variance.

TABLE II

ANALYSIS OF VARIANCE OF THE PER CENT. CORRECT COMPLETIONS OF BOTH OF TWO ITEMS PRESENTED SIMULTANEOUSLY FOR DIRECT LOCATION

Source	*Sum of squares*	df	*Variance estimate*	F
Instruction ..	10·03	1	10·03	—
Conditions ..	71·17	2	35·58	—
Interaction ..	413·38	2	206·69	1·9
Within cells ..	4206·17	30	140·21	
Total	4700·75	35		

From Table I it can be seen that some simultaneous pairs were apparently successfully located. Although their total number was small, the important thing to be determined is whether or not they were appreciably more numerous than might be expected on a chance basis. For the purpose of analysis, unfortunately, exact computation of chance probabilities is impossible since the correct location of one or more items considerably altered the odds of further guessing of correct locations.

Even though exact determination of probabilities for the successful location of two simultaneously presented pairs of items was not possible, it was possible to

calculate some approximations. This was done for all three conditions. In every case the probabilities were figured for the circumstance that provided the most unfavourable opportunities for correct guessing. As an example, for Condition I it was assumed that one-half of the directly given items were located correctly (e.g. all of the visual or all of the auditory). In this case, that accounted for two of the six items to be located. Since only the direct items are being considered here, the subject had four guesses to locate correctly the remaining two locations. He knew which of the five categories of items (towns, lakes, parks, buildings, and highways) were to be guessed from, and how many of each category were to be located. This information was given him before the start of the experiment, it will be remembered. Assuming further that only three of the five possible categories were used, it was possible to ascertain the average number of simultaneous pairs that would be expected to be located successfully for a given map. This theoretical frequency would be the lowest that could be expected if all of the maps and all of conditions were as unfavourable as possible for making correct locations by guess alone. It is perhaps unnecessary to point out that many of the maps and conditions provided probabilities considerably greater than those considered in this type of evaluation.

Using this method of analysis, it was determined that for Condition I an average of 0·34 correct simultaneous locations could be expected per map. For Conditions II and III, the figures were 0·47 and 0·51, respectively. Since there was a total of 60 maps for each condition (both groups), the expected numbers of correctly located simultaneous pairs would be 20·4, 28·2, and 30·6 for the three conditions. A look at Table I shows that the obtained figures were 14, 25, and 24. Therefore, it seems fair to conclude that subjects did no better than would have been expected from random guessing.

Effect of instructions. The fact that no more successful completions of simultaneously presented items were made by the "instructed" group than by the "uninstructed" one is subject to two interpretations. Either the "uninstructed" subjects became aware of the simultaneous presentation in the practice trials or early in the experimental trials, or else, under conditions that provided no opportunities for rapid shifts of attention, only one perception at a time was possible, and the instructions were of no assistance. That the latter interpretation is the correct one is illustrated by the answers to the questions put to the "uninstructed" group at the end of the experiment. Of the 18 subjects in this category, not one volunteered the correct answer when asked what they could tell the experimenter about the presentation of the relevant items of information that had appeared in the visual and auditory series. When asked directly if they knew that the presentation had always been simultaneous, 2 replied that they had noticed it happening once or twice, whereas the other 16 denied ever having noticed it. Many were vehement in their denials and expressed outright surprise, and in some instances, sheer disbelief that such had really been the case.

In the light of this result, it seems fair to state that the reason for the lack of difference between the two groups in the above analysis resides in the inability of the "instructed" group to take advantage of their knowledge.

Total items. Another way of considering the data from the items about which direct instructions for location were given is to consider the total percentage of such items correctly located. Table III presents this information without regard to the two groups of subjects. Here it can be seen that in no case were more than 50 per cent. of the items presented correctly located. If for single-modality presentation, the task proved so difficult that only a relatively small percentage of items could be located anyhow, this result would not prove very meaningful. However, the speeds

of stimulus presentation were very slow (106 words per minute) and the single modality task was well within the capabilities of a normal observer. Evidence of this is provided by some of the individual results. One subject correctly located all of the visual presentations and none of the aural ones, whereas several others while locating only one or two of the visual or aural presentations correctly located nearly

TABLE III

PERCENTAGE OF DIRECT ITEMS CORRECTLY LOCATED (Visual and Auditory)

Condition I	*Condition II*	*Condition III*
41·7	45·8	44·6

all of the items presented in the other modality. It seems safe to say, then, that not only is there no evidence to show that simultaneous perceptions were accomplished in this situation, but, on the contrary, there is some possibility that actual interference was produced by the simultaneous presentations.

Modality differences. The number of correct responses mediated by the visual and the auditory channels for the directly presented items provides some interesting results. These data are summarized in Table IV. Here it can be seen that the visual

TABLE IV

TOTAL NUMBER OF CORRECT COMPLETIONS OF DIRECTLY GIVEN VISUAL AND AUDITORY ITEMS FOR BOTH EXPERIMENTAL GROUPS AND FOR THREE CONDITIONS OF INFORMATION

Condition	*Group*	*Visual*	*Auditory*
I	Instructed	33	13
	Uninstructed	38	16
II	Instructed	50	42
	Uninstructed	41	32
III	Instructed	53	49
	Uninstructed	81	31
Total		296	183

completions are consistently greater in number than the auditory ones for both groups and for the three conditions utilized in the experiment. An overall test for the significance of the difference between the visual and auditory scores considered without respect to groups or conditions yielded a critical ratio of 3·1 which indicates significance ($p < 0{\cdot}002$).

These latter results are in line with those reported earlier by Mowbray (1953) relating to the dominance of the visual channel over the auditory with conflicting simultaneous combinations. The explanation for this visual dominance presumably resides in the nature of the auditory and visual presentation. The constantly moving visual display required an active effort on the part of the subject to the apparent

detriment of reception via the other channel. Such a discrepancy would probably not exist were it possible to accomplish simultaneous perceptions. All of the results from this experiment suggest that complex perceptions involving language cannot be effected by different sensory modes at the same time. There is no indication from this experiment what the exact limits of complexity may be. It is conceivable that very brief symbolic material, such as letters and numerals or simple words, may be handled effectively by two channels at the same time when presentation is precisely synchronized. Further research is needed on this point.

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MISCELLANEA

A PROJECTION TACHISTOSCOPE

BY

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It is generally agreed that a well-designed tachistoscope should satisfy the following requirements (Vernon, 1937):

1. Clear presentation of the stimulus for a measurable and variable interval of time.
2. Measurable variability of stimulus intensity.
3. Neutral exposure field, free from positive and negative after-images.
4. No variation in the intensity of the exposure field when the exposure takes place.
5. No distraction from movement of mechanical parts of the apparatus.
6. Comfortable viewing, the subject sitting in a normal relaxed position and using both eyes.

Most of the designs of which the writer is aware either fail conspicuously to fulfil one or other of these requirements, or else are so complicated in design that, though in theory they should satisfy the requirements, they still have serious deficiencies in practice. For instance, it is difficult to see how, using either the Dodge tachistoscope or the Vincent-Wolters tachistoscope, it is possible to avoid some background flicker accompanying the exposure of the stimulus; and in both cases the subject is required to peer through a hole into a box, in which the intensity of light differs from that outside, so that he almost always has a feeling of strain after the first few exposures.

The basic difficulty seems to be that, if one thinks in the conventional way of dark stimulus figure on a white ground, it is necessary to make complicated provisions for maintaining an equivalent white ground during the pre- and post-exposure periods, and for making the change-over unnoticeable. This conventional approach is abandoned in the present design, and the subject views a light stimulus-figure on a relatively darker ground. The great simplification introduced by this simple step is attributable to the fact that light can be interrupted physically, whereas darkness obviously cannot. For most practical purposes, it appears to make no difference to the subject whether he is asked to view a light stimulus on a dark ground, or *vice versa*. This is, after all, what he does every time he looks at a blackboard.

General design. The apparatus to be described is in principle extremely simple. It consists of a standard 35 mm. lantern-slide projector used in conjunction with a shutter. The slides used are negatives, which let light through only in the "figure" which constitutes the stimulus. When projected, the "ground" remains constant, simply because no additional light falls on it during exposure. Writing or drawing thus appears in white against a relatively darker background.

Slides. Stimulus material is drawn with black ink on white paper, and photographed, using a 35 mm. camera. The film is developed to make negatives, which are mounted and used as slides. For line drawings it is important to use high contrast, fine grain microfilm (as used by libraries), since only with this type of film can sufficiently contrasted negatives be obtained.

Projection screen. Using a modern high-power projector, the stimulus can be shown on a neutral grey screen at a distance of about ten feet in normal artificial room illumination. By choosing the correct shade of grey, after-image effects can be almost entirely eliminated.

Shutter. For many purposes, a camera shutter placed in front of the projector lens will be found adequate. The shutter requires no lens, and should have an internal diameter of approximately 1 inch. A good quality variable-speed shutter of the Compur type should be sufficiently accurate to allow calibration in units of approximately 1/100 sec., in a range between 1/100 sec. and 1/10 sec. Since intensity may also be controlled (preferably by using grey glass filters or wedges), this range should usually be sufficient. It is also advisable to use a heat-absorbent glass filter between the shutter and the projector, to prevent the shutter from warming up.

Where more accurate control of exposure-speeds is required, some sort of rotating disc shutter may be preferable. In practice, we have found it convenient to have a metal disc with variable aperture situated between the condenser lens and the slide carrier, and running as close as possible to the face of the slide. The disc is driven by a constant speed motor at about 1 rev. per sec., and is approximately 14 in. in diameter. This allows calibration of the exposure-time in units of 1/400 sec. or even less. The disc also rotates slowly enough to allow the experimenter to open and close an ordinary camera shutter (set to B), so that the stimulus, instead of recurring, is only projected once.

In addition to satisfying the main criteria, this apparatus has several other advantages. Its construction and operation are simple. Use is made of standard equipment, which is still available for other purposes. When investigating subjects one at a time, using a photographic shutter, each subject may operate it himself, by means of a cable release. This minimises the possibility of temporary lapses in attention or blinking during the brief stimulus presentation. The stimulus can be viewed, however, by more than one person at a time, and the apparatus is therefore suitable for demonstration purposes. Eyestrain is minimal, since the apparatus works well in normal lighting conditions. The intensity of the external light source should, however, be kept constant, since the eye is extremely sensitive to changes in the relative intensity of the stimulus. The apparatus may also be adapted for the continuous exposure of stimuli at very low levels of intensity, and can thus be used in the investigation of perceptual threshold phenomena.

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